MASTER

The smart machine for living
an extensive research on a prefabricated, customizable housing unit

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An Extensive Research on a Prefabricated, Customizable Housing Unit

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Justification
This is a publication within the graduation studio Smart Living, initiated by the chairs of Architectural Design & Engineering, Design Systems and Building Physics and Servises.

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This thesis marks the end of a one-year research/design master project at the Architecture building and planning department at the Eindhoven University of Technology (TU/e), the project was highly motivated by a controversial slogan from the visionary architect Le Corbusier “A House Is a Machine for Living In”. As I was always inspired by Le Corbusier’s designs and implications in his projects and his contributions to modern architecture, I planned to investigate why he believed houses should be built and designed the way machines are manufactured.

I was encouraged to put all my effort on researching the machine for living when I made a statement in my first presentation in the graduation studio, which was “Smart house is a machine not only on the façade but also in the infrastructure which should act like a living intelligent machine to incorporate with its inhabitants lives.”, then I could simply link the statement to Le Corbusier’s slogan. Then a million thoughts rushed through my mind but the dominating thought which shaped the research was to propose a “smart” machine for living which could be modified for different tastes.

The research was then followed by an in depth analysis of the machine which was directly linked to mass-produced houses of the late nineteenth century, as strange as it was to find out that the machines for living from Europe were advertised more in the United States I was then steered on a path to study machines for living in the US which were called “houses of tomorrow” there.

The basic principles of the machine for living were then analyzed to find the shortcomings and the problems related to them to reach a point in which a new design could be realized to enhance the characteristics of the machine.

In this point I was inspired enough that I couldn’t wait to start my design, the high rise building that I was able to design is a principle in which it could be placed anywhere and due to its customizability the housing units could be designed to incorporate the customer’s needs.

I wish I could have more time to design each and every part of the project to the smallest detail and it is a pity I could work on this project for only a year not more, I hope I can one day finalize the cantilevering aluminum unit with detailed structural calculations.
I take this opportunity to express my gratitude to the people who have been influential in the successful completion of this project.

I would like to offer my special thanks to my professors Maarten Willems, Bauke de Vries and Patrick Teuffel, for their invaluable support and guidance from the beginning of my research throughout the final stages of the thesis.

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Lastly, I would like to dedicate this thesis to my mother and my late father for making this possible, And also to my bright sister Roody for believing in me.
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The re-interpretation of a long lost modernist idea of the Swiss-French architect Le-Corbusier on mass-produced housing (machines for living) is the main agenda in this project. The machine house principles are implemented in a 21st century high rise building trying to specifically address the needs and demands of the customer rather than the architect or the contractor. The project is tried to be as adaptable to different tastes as possible while still embracing the mass-production and mass-customization idea. The project was designed with generic qualities which will allow the principles to be adjusted to any situation and location in a high-rise or a low-rise building. The result from this research is a prefabricated aluminum unit which could be connected to a steel grid structure while cantilevering from one side. The unit is designed to be dismantled to various parts and be reused in future. The modifiable units are comprised of different segments that can be produced in factory controlled situations and be transferred to the site for final assembly. The assembled units are then transferred to their destined locations with a permanent crane which stands on one side of the main structure. The crane is itself a custom made product designed only for this structure.

All the contributions that have been made in this project were to enhance the living experience from the machine for living and to change how prefabricated houses are being perceived by people. One of the main issues with the machines for living that became the main objective in this thesis was its lack of customizability. Since mass-produced houses are perceived as neglected container park replicated shoe boxes with uninhabitable qualities, it was specially important to find a structural solution to change this perception to reach the ultimate customizable housing principle.
Structure of the book

This research will look into various machines for living projects and compare them on the basis of principle set by Le Corbusier and his machines for living, and then the research will delve more into the proposed principles introduced by Le Corbusier in his book Towards a New Architecture about the machine concept revealing the true characteristics of the machine. Furthermore the focus of the research will be on mass-production houses with an insight into projects introduced in the book of Home Delivery: fabricating the modern dwelling. The field of research in the book is history, while the research will also include a design analysis that attempts to evaluate contemporary mass produced projects. The final result of the research will be a comprehensive design for a mass produced high-rise structure.

Introduction

The machine house, one of the main ideas of modernist architecture, reflected the living environment as a machine with an architectural form that was shaped and extracted from the factory buildings built in the industrial revolution era. The main character who studied the machine and brought the idea to life was the ‘engineer kind’ architect Le Corbusier. Fascinated by the machines, automobiles, airplanes, and ocean liners, he sought to bring the seamless and smooth response to requirements he witnessed from living machines to architecture. His conceptual attempt was to design for people through prioritizing their needs as users –as he thought- with certain, predictable behaviors identified by the architect. Because of the disadvantages associated with this ‘user’ identity for people, in time it altered to a new character as the ‘consumer’ with diverse desires and needs that had to be met with different solutions (GÜNLÜ, December 2007). The industry started to investigate the desirable for today’s man with complex studies on people, their behavior, and their perception to integrate his needs within architectural design for the future house.

The need for a more customized house for the ‘consumer’, persuaded architects to reach out to technologies in other industries, the route to a computerized flexible house which could adapt based on user perceptions, found its position in houses in the recent years as the smart house. The term ‘home automation’ in general is a concept in which self-controlled houses become masters of their own functions to fulfill the consumer’s needs. The smart home is still considered as an ongoing research to reach the ultimate flexible house.

Smart home laboratories are following a number of
investigations to integrate the solutions they have found, in housing systems; the ideology seems close to what the modernist machine concept was, to design for people, modernist architect believed “all men have the same needs” (Le Corbusier, 1923/1986), predicting standards for house as a machine, instead in the new ideology they are trying to exclude this standardized thought to reach a more customized and individualized system for each individual, the difference however is in the manner of human studies, human in the machine age was studied based on his physical needs and features, instead today he is studied as deeply as to his mind, beliefs, perceptions, down to his deepest privacies.

A new era began in architecture after the publication of Le Corbusier’s famous slogan “A house is a machine for living in”, for many architects whom followed Le Corbusier the machine house was a driving force in their principles. A replication method for construction was envisioned by Le Corbusier which had its roots to that of the mass production in car manufacturing factories like Ford. His machine was a standardized and replicable principle for mass-produced housing envisioned to be built for the modern man living in 20th century. After World War I the demand for housing exponentially grew after vast devastations in different European countries, it was in this period which pre-fabricated and mass produced houses became the perfect solution for the housing problems.

But the reality in long term was that “mass-produced houses or off-site fabricated houses come to be associated with products from trailer parks.” (Kieran & Timberlake, Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction, 2004)

As Le Corbusier was criticized by the architecture community, admitted that the “right state of mind” did not exist for his new, mass-produced architecture and he also predicted that in 20 years it would be possible to see his vision being constructed after achieving the right construction methods in architecture. He was right we achieved the predicted methods, but the “state of mind” never reached a rational level for people to accept living in an industrialized type of living which was linked to low quality trailer park boxes. What Le Corbusier and other associated successor architects did not realize was that production toward a common, repetitive look for all products and customers with a vast different taste is always opposed to individual preferences, cultural differences, location associated characteristics.

The smart home concept emerged more visibly since the availability of developed information and telecommunication technologies, the technologies which allow the users to integrate a range of automatic services within the home environment; the goal is to literally adapt the house to its users to create a feeling of personal belonging with the help of atomization. The wide range of user centered individualized products and possibilities introduced
new potentials in housing principles. However today the idea of living in an automated (smart) house is still undesirable due to unfamiliarity for people and the lack of access for everyone. This is resulted because of the very high price of integrating these smart technologies in houses and also it is due to the fast evolution pace these technologies are involved with which makes these machines outdated after a short period of time. Based on these assumptions this thesis have been trying to conceptualize a different meaning to smartness in design rather than smartness in technologies implemented in design. The smartness in design which could be defined in customizability of a product.

The last century witnessed a broad variety of social housing which were basically categorized as mass produced housing developments aimed for the middle class families. After the emergence of smart technologies and their potentials, These smart potentials led the prefabricated housing industry to seek the possibility for different systems in which more signs of individualization could be visible not only in the final interior organization of the house but also in the design process.

This research is focusing on the prefab and mass-production qualities of the machines for living from the first initiation in 1920’s to the houses of tomorrow in United States, which displayed the qualities more practically in different circumstances, then the qualities derived from indicated projects will be compared to more recent prefab projects in the late 20th century in a table in which from this comparison a preferred quality for the ultimate mass producible house of 21st century will be acknowledged.
Research question

Based on the assumption that the smart home concept has emerged more visibly since the availability of developed information and telecommunication technologies, this research is trying to reach the ultimate “machine for living” idea and principle from modernist architect-Le Corbusier- based on the general visionary characteristics of the machine which was evolved from 1920 to 1965 by the controversial architect, intended for the year 2013 alongside the emergence of smart home technologies and customizability in architecture.

The research question has been shaped by identifying the shortcomings of the basic idea of the machine for living and the projects built based on the idea to regain what was meant to be accomplished from the idea in order to shape a new concept or system aimed for a 2013 mass-produced living space.

How is it possible to enhance the characteristics of the 1920’s “machine for living” concept to reach the ultimate mass produced housing principle aimed for a 2012 potentially high rise smart building?

The main research question is then investigated with a series of sub questions, to reach a conclusion in which it could be a new smart principle for the indicated machine house.

1. What are the general conditions and characteristics of the machine for living?

2. What are the basic characteristics of a Corbu-Style modern architecture in mass produced residential buildings (machines for living), beside the famous five points in his principles?

3. What are the general believed deficiencies of Le Corbusier’s prefabricated, mass-produced machine for living idea?
Context

Figure 1 Le Corbusier
A great epoch has begun. [...] The problem of the house is the problem of the epoch. [...] The architecture has for its first duty, in this period of renewal, that of bringing about a revision of values, a revision of the constituent elements of the house. [...] Industry on the grand scale must occupy itself with building and establish the elements of the house on a mass-production basis. We must create the mass-production spirit. The spirit of constructing mass-production houses. The spirit of living in mass-production houses. The spirit of conceiving mass-production houses. (Le Corbusier, 1923/1986, p. 227)

The machine house, to be exact “machines for living in” (Le Corbusier, 1923/1986), was a famous idea stated by Swiss-French architect Le Corbusier in his book ‘Towards a new architecture’ as a proposal for mass-production houses for post war social housing in Europe. His approach was to find a standard for time and cost effective modular units for 1920’s modern man. While claiming “all men have the same needs” (Le Corbusier, 1923/1986, p. 136) sought for the perfect standardized houses which could also be replicated to build a multi-story housing apartment. He also believed in creating the state of mind for living in mass-produced houses. He thought of machines as tools that responded to requirement smoothly which could get the tasks done without any interruption and their sole purpose is to service mankind; assumed houses should also inherit the same principle, to be designed for people.

If we eliminate from our hearts and minds all dead concepts in regard to the houses and look at the question from a critical and objective point of view, we shall arrive at the “House-Machine” the mass-production house, healthy (and morally so too) and beautiful in the same way that the working tools and instruments which accompany our existence are beautiful. (Le Corbusier, 1923/1986, p. 227)

Le Corbusier states the existing problems of houses in 1920s’ by directly proposing some questions containing the deficiencies he thought had to be changed in houses to approach the concepts of his claimed machine for living. These problems were the ones he believed the public was struggling with and were only limitation to “the progress”, and the changes would led the industry to modern man house or the machine for living. His proposed slogan to create the right state of mind was summed up in the same book under the title Manuel de l’Habitation (which appears at the end of the chapter on aircrafts).

-Demand a bathroom looking south, one of the largest rooms in the house...
-Demand one really large living room instead of a number of small ones...

-Demand bare walls in your bedroom, living room and your dining-room. Built in fittings to take the place of much of the furniture.

-If you can, put the kitchen at the top of the house to avoid smells.

-Demand concealed or diffused lighting.

-Demand a vacuum cleaner.

-Buy only practical furniture and never buy decorative “pieces”.

-Keep your odds and ends in drawers or cabinets.

-The gramophone or the pianola or wireless will give you exact interpretations of first-rate music.

-Demand ventilating panes to the windows in every room.

-Teach your children that a house is only habitable when it is full of light and air, and when the floors and walls are clear.

-Demand a separate garage to your dwelling.

-In his book toward a new architecture Le Corbusier was seeking to bring forth the idea of standardization for housing, to reach a standard in which it could comply with all its “users”, he believed the occupants were literally only users with the same feelings and needs, “all men have the same needs.” The idea of standardization was based on the considerations of living situation and living environment of that period. After world war one the demand for houses exponentially grew to the point that idea from production in car companies was an ideal solution to the problem.

Le Corbusier assumed that because car industry had to follow a standard, the competition was the driving force to a search for perfection and harmony which he believed was the reason for its evolvement. A standard will evolve in accordance with different aims.

If the problem of the dwelling or the flat were studied in the same way that a chassis is a speedy transformation and improvement would be seen in our houses. (Le Corbusier, 1923/1986, p. 133)
Ford model T

The evolvement in motor-car industry was considered as a challenge to house design and its principles.

At the beginning of the 20th century cars were luxury products for the rich, most of the models produced then were complicated machines requiring certain expertise to drive it. Henry Ford was determined to build a simple, reliable and inexpensive car for the average American society. From his determination the Ford Model T and the assembly line were innovated to revolutionize the production line and the world we live in today. (Figure 2)

What was different in the Ford Model T was not the car per se was the method it was manufactured with. A car built for a different target group and within the economic reach of the average American. The method was designed so that it would reduce the cost of the car while the profit and the earnings were to be achieved in a longer time and more steadily. This was the true first impressions of mass-production in the industry which attracted the architects in Europe.

The main reason in success of Ford’s Model T lied behind the development of the assembly line that increased the efficiency of manufacture and decreased its cost (Figure 3). Henry Ford did not conceive the concept, he perfected it. Before a production line was conceived cars were built in a different manner, they were individually crafted in a slow and expensive pace. In the assembly line the whole process was reversed, instead of workers going to the car, it was the car that reached the workers which performed a certain task on each car over and over again. In this method the repeated process performed by each worker could increase the quality of the product and also reduce mistakes and the assembly time of the product which in this case was the ford model T.

The Dream of Mass-production

What was interesting for Le Corbusier and other 20th century architects was the compelling image that ford represented, The unrelenting devotion to replication. Le Corbusier felt the power of this idea and promoted its adaption by architecture. He believed the reduction to “object types” not only would build a more beautiful and powerful physical world but they would cost less and would broaden the working class’s access to well-designed accommodations of higher quality, whether they were cars or buildings. (Kieran & Timberlake, Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction, 2004)

Some buildings that are believed to be an initiative to the concept of the machine for living and the continuity of the Ford Model T’s mass-production concept will further be explained.
Figure 3 Ford Model T assembly line
From Citrohan mansion to the home of tomorrow

Citrohan mansion

The Citrohan mansion (not to be mistaken by Citröen) was conceived as a test on a home series that could be constructed from standardized components, after a ten year study of the principles and the announcement of five points of Le Corbusier, Citrohan presented a pretext to the aforementioned points and also served as a machine for living. The house was designed to be built in any country relying on the standardized structure system dom-ino which was developed in 1914, a structural system completely independent of the floor plans, a framework which was to be fabricated out of standardized elements to be attached to one another (Girsberger & Boesiger, 1960), more importantly it was a visual summation of the architect’s anticipated five points (Bergdoll & Christensen, 2008). The Citrohan mansion was presented within three basic prototypes (Dom-ino, Monol, Citrohan), as a housing type that could be built in series like machines, Citrohan was the most developed throughout his career. It was one of the basic themes of Le Corbusier’s interest in industrialization and new methods of housing from which was expected to emerge an economic house for all. (Figure 4)

For Citrohan prefabrication was also considered to reduce its utilization or minimize the equipment necessary for building the house.

L’Esprit Nouveau pavilion

In 1925 Le Corbusier publicly presented the idea of modern housing he previously introduced in Towards A New Architecture in exposition internationale des arts decoratifs et industriels modernes in paris. Le Corbusier and Pierre Jenneret erected an actual two story apartment unit with integrated garden, open plan double-height living room, mezzanine bed rooms above, and a glass wall at one end, which was believed to be the first prototype of the machine for living. Multiple standardized units of mass-housing conceived as a minimal “dwelling type, of exclusively industrial execution, using a system of standard elements” (Marcus, 2000, p. 26).

The house was simple, unornamented, reinforced-concrete and glass structure, served as a model for an urban mass-produced building type Le Corbusier envisioned called immeubles-villas. The dwellings were imagined as completely separated apartments joined side by side to other identical apartments to shape a multi-story apartment block. The Esprit Nouveau was a pure example of Le Corbusier’s universal living unit aimed for a modular housing.

Figure 4
Maison Citrohan
The home of tomorrow, a true machine for living

The machine for living concept which initiated from Europe happen to affect American architects and designers as well, the idea started to shape after World War I because of the growing need for housing spaces in the country. Therefore the mass-production housing idea started to influence American architects and also resulted in the emergence of new designs based on Le Corbusier’s famous slogan. Horrigan and Corn (1984) believed that architects took inspiration from machines – their clean cut, uncluttered surfaces, direct and purposeful design and sheer modernity. (Corn & Horrigan, 1984)

The modernists rejected traditional building materials in favor of concrete and other industrial materials; adopted the smooth, undecorated surfaces and flat roofs found in industrial products and buildings, and broke the discrete room structure of houses into free-flowing interior spaces in the matter of Wright. (Corn & Horrigan, 1984, p. 65)

Furthermore the modernists argued that these houses should not only be inspired by the machines but they should also be made by them. The prefabricated houses and the idea behind them were rooted from this belief.

During this period (1920s) a number of architects who were disciplined under the modern principles of Le Corbusier and generally modernity moved to America and introduced their machines for living.

One of the first architects who was able to build his prototype was Richard Neutra, a German architect who emigrated to America in 1923. The house was designed and built for Dr. Philip Lovell who as (Corn & Horrigan, 1984) states “could see the future”.

A tense and airy structure stretched out over a Hollywood canyon which had a welded steel frame, flat roof, ribbon windows, and sprayed concrete walls, thus emulating industrial construction methods and using industrial materials. Neutra used Model T headlights for lighting which was a tribute to Henry Ford, the mass production genius. (Figure 5)

The house clearly didn’t display the machine for living main quality which was an inexpensive shelter, industrially made and produced for the masses (Corn & Horrigan, 1984), it was indeed only a machine mansion.

The first house of tomorrow designed based on the machine for living principles was ‘Dymaxion House’ designed by Buckminster Fuller in 1927 whom was not an architect but a self-taught engineer. A cheap, mass-produced, futuristic house which was more responsive to the machine-dominated imperatives of contemporary life was designed and fully exploited available technology. It was believed to be a true machine for living.

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*Figure 5
Richard Neutra: Lovell House, Los Angeles, 1927-29*
Fuller based his house on a central aluminum mast from which transparent glass and casein walls and inflated rubber flooring was suspended by metal cables (Corn & Horrigan, 1984) since the house of tomorrow was thought should be lightweight and mobile. (Figure 6)

two bathrooms, a self-activating laundry unit that would deliver washed and dried clothes in 3 minutes, sewage disposal tanks, an electric generator, an air compressor, a humidifier, a kitchen with every conceivable appliance, two small bedrooms with pneumatic beds with neither sheets nor blankets, these being unnecessary in the perfectly climate-controlled house (Corn & Horrigan, 1984)

Fuller claimed since he was able to eliminate drudgery (Corn & Horrigan, 1984) by supplying machines inside his house, “The real individualism of man and his family may be developed” and also he thought “creation will set in as never before”. The house had a “get on with life” room, equipped with type writer, calculator, telephone, Dictaphone, television, radio, phonograph, and mimeograph machine. (Figure 7)
The dymaxion house of tomorrow was only exhibited in a scale model but the first full-scaled house to finally gain the national fame was a building designed by Fred Keck built for the Chicago century of progress fair in 1933. The house contained a recreation and work room, a garage, and a hanger for family airplane. A twelve-sided, steel-frame, completely glassed-in structure built around a central utility core. This house was no less than the Lovell house, it was also an expensive house to build. (Figure 8)

The Crystal house was another project designed by Keck to reach the inexpensiveness quality of the machines for living and also a proposal for mass-production houses. It was a pure glass cube suspended within an external structural steel cage. (Figure 9)

Most of these projects and the ones appeared during this period which were also claimed to be conventional prefabricated housing projects remained as unrealized projects in spite of the fact that they believed prefabricated houses will provide cheap, efficient construction methods.
Figure 8
House of Tomorrow by architects George Fred Keck and William Keck

Figure 9
Crystal House (1933–1934)
Based on the research implemented on the major projects categorized under machines for living during 20's and 30's in Europe and united states of America mentioned above and a detailed survey on Le Corbusier’s housing projects until 1950's, the basic characteristics of the aforementioned concept were derived. Additionally because mass-production houses are the main focus of this research the characteristics selected for the concept are mostly concerned with the context.

Since the main idea stemmed from Le Corbusier’s vision unsurprisingly the basic characteristics of the machine, which evolved from 1920’s to 1930’s, are identical to what is found in the original machines for living. Additionally it is important to indicate that Le Corbusier’s five points were also organized to complement the machine ideology - the domino structural system played an integral part in the birth of the machines for living that anticipated the architect’s five points, an architectural doctrine that he would articulate more than a decade later in written form (Bergdoll & Christensen, 2008) - which was applied again and again in different structures and became an influential part of modern architecture. Therefore the five points (1.Columns 2.Roof gardens 3.Free plan 4.Long windows 5.Free façade) definitely are vital qualities defining the machine for living, furthermore the other characteristics found during the research within the idea of mass-produced houses are listed below.

**Mass-production**: the design should enable the industrial production of high-quality components in large numbers in an off-site manner to improve its quality, affordability and accessibility. (Arieff & Burkhart, 2002, p. 13)

**Time effective**: the building should not only demonstrate a prefab quality but it should also present how well time was spent on attachment of the structure.

**Affordable (Cost effective)**: affordability is one of the most important aspects of the idea behind the machines for living in America (the house of tomorrow) and also in Europe demonstrated by Le Corbusier in Pessac 1925 and several other projects by the architect.

**Universality**: the mass produced houses without doubt implement the quality to support universality, to be built in any country.

**Standardized elements**: a home that could be constructed from standardized components (prefabricated off-site) in series to be attached to one another (on-site) to increase the finishing quality of the products.

**Lightweight and mobile**: as introduced in the dymaxion house and largely promoted by the architect, mobility was an important characteristic for the dymaxion
house, subsequently being light weight also became a key feature for the mass production houses of that era. Although these qualities were considered quite new and innovative at the time, today they are more categorized as general conditions a mass produces house should cover. Therefore in order to understand what has been altered to improve these qualities in today’s mass-produced houses, the research will continue to investigate more pioneer projects which comply with the context and the research question.
Prefabrication in industry and architecture

Defying gravity

The assembly of large objects used to be dictated by the laws of gravity. Buildings would typically start with a structural frame, proceed from the bottom, and move upwards hierarchically, adding elements until completion. Today, the industry has moved toward nongravity-based processes where pieces of the object are framed and outfitted independently of the whole and brought together only at the final assembly.

Traditionally architecture has been shaped and built in a sequential process in which parts are put piece by piece together to shape a building or a monument. Parts are defined, transferred to the site and then assembled from ground up. Prefabrication in architecture has and will be a dream that attempts to change the traditional approach. But the main concern is how it could be determined to replace the traditional methods of construction. Introduction of simultaneous background processes in which fragments of an individual building built simultaneously along each other, for instance, the first initial structural elements of the building and parts of the façade, could be an answer to the problem.

The background process which we do not see breaks the laws of construction, gravity as an obstacle or perhaps a driving force compelled buildings to be brought up from the ground up in a traditional sequence from foundation to finish, from building to building the process tends to remain the same. The way we address gravity predicts how the product will be built whether it be a ship, airplane, car or a building. It may not be common to mention these products in the same context but all of these have one thing in common, they are all built from the bottom up. Gravity plays an integral role in bringing all materials and parts into an ordered group that is the structural frame which holds all the other elements together.

Throughout history the difficulties concerned with gravity and production with large elements and moving them have dictated that parts arrive at the site in numerous numbers and then be assembled with the traditional sequence: foundation, frame, skin, systems, finish, equipment. Today in the industries mentioned above the whole process is separated into independent ones, as they no longer first build the structure frame; instead each product is being built gradually in separate parts, parts in which have been fitted with all the equipment in advance, in another location or a location near the assembly site or if needed in controlled factory built conditions. In this procedure parts will be transported to the aforementioned assembly site for the final installation which only includes joining the larger elements together. Therefore parts are not treated in the traditional sequence but instead are treated in an entirely different manner that allows each separate party involved in the process to produce a product with a considerable higher quality. Inspections can be undertaken in the work space and if a problem was
found it can be corrected.

The non-linear process promotes shorter overall construction duration since the fragments are in simultaneous production and the building condition can be optimized so that significant climate changes would not affect the process because parts can be built indoors. The work space which is an important part in defining the working condition can be adjusted to a comfort level; this would mean avoiding severe working conditions that results in a declined labor costs. The total work time to build a part separately rather than building it on site reduces which also reduces the total labor cost. Required equipment is nearby, so there is no need for transferring equipment to the site. With this approach having a final assembly date is not even necessary; the arrival of each part to the site is an initial to the final assembly. A predefined schedule can be a beneficial factor for assembling parts, because parts can be assembled simultaneously as like they were built in the same manner.

Prefabrication: a century of failure

The dream to convert modern architecture into a commodity to turn away from elitist and toward universal was a substantial portion of modern architectural theory. Although the dream has risen again with each generation since the beginning of the twentieth century, it has failed to materialize with each successive attempt. Italian architect St. Elia believed each generation must destroy its built inheritance and rebuild it with its own architectural definitions, Le Corbusier’s machine for living molded on American automotive production, numerous factory produced houses of the World War II era all failed to provide lasting legacies.

The predominant reason for these failures was the restrictive nature of the agendas that underlay each successive effort.

“Each attempt to transform architecture into commodity had political, programmatic, procedural, and stylistic agendas that were narrowly defined. Each fervent belief system was narrowly monotheistic and so had little widespread, enduring, self-sustaining applicability” (Kieran & Timberlake, Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction, 2004)

Dreams of an off-site architecture were motivated by political agendas and the difficulty lies in the cyclical nature of politics. While national and local political postures are altered every few years, architecture production does not thrive on rapid change. The production and support structures required to build are slow to evolve and expensive to implement. When these structures are tied to politics, the lack the continuity of capital expenditure and procedures required to sustain an enduring architectural agenda.
Mass-produced prefab housing projects of the late 20th century

Based on the research question and the level of perfection in order to delve more into the subject a number of projects have been selected from the book of *Home Delivery: fabricating the modern dwelling*, at The Museum of Modern Art, (Bergdoll & Christensen, 2008). Since the book has focused on the evaluation of the past, present and future of the prefabricated house, the projects could be categorized based on the research’s criteria. The reasons why these projects were selected was basically based on the fact that they were high rise prefabricated houses or have the potential to be used or defined later as high-rise buildings with the closest qualities to a machine for living. The projects will then be investigated for certain qualities in a table.

### Habitat ’67

Habitat 67, or simply Habitat, is a model community and housing complex in Montreal, Canada designed by Israeli–Canadian architect Moshe Safdie. The project was constructed entirely of interlocking modules, and each unit had small yet comfortable private quarters with access to a spacious private garden. The system proposed by Safdie was of great importance since modules were interlocked and woven in a horizontal direction (Figure 11). (Bergdoll & Christensen, 2008)

### Unite d’Habitation

Built twenty years after the first Citrohan prototype, the Unite d’Habitation is believed to be as one of Le Corbusier’s most accomplished realizations. It was a demonstration of the famous “vertical cities” supplied with internal shopping avenues. In the design process Le Corbusier envisaged to possibly develop the flats in a mass produced manner (off site) in a factory and slotted into the structural frame like a wine rack. Each unit contains a double-height living space with a deep balcony. (Figure 10) (Davies, 2005)
Figure 10
Unite d’Habitation
STELCO Catalog Housing

A steel housing prototype design by Barton Myers consisted of a system of steel column sections, hollow tube beams and a number of different sandwich panels, all on a 3-foot square module; these sections were framed in a host of combinations with the potential to be stacked as high as three stories. The most amazing aspect of the proposal was the system in which catalogue-ordered parts could be assembled by two unskilled persons. (Bergdoll & Christensen, 2008)

Zip-up Enclosures NOS. 1 and 2

A housing “resource” designed by Richard and Su Rogers proposed to be expandable and portable. Inspired by construction of airplanes, boats and cars the body is combined with the chassis as a single unit and the vehicular “skin” provides its own structural support. The floor, walls, and roof components were to be fabricated off site in separate pieces and then attached on site to create the structural ring. Furthering the enclosure’s customizability would be it’s ability to zip up with other rings adapted to the spatial needs of the costumer (Figure 12). (Bergdoll & Christensen, 2008)

Nakagin Capsule tower

The tower is a superstructure with numerous prefabricated units “plugged in” with qualities of adaptability and flexibility designed by Kisho Kurokawa. The tower was initially designed as a hotel to provide affordable accommodations for single businessman. Each unit (capsule) were prepared off site and hoisted into place by crane onto the fourteen-story superstructure and its concrete core shafts of vertical circulations (Figure 13). (Bergdoll & Christensen, 2008)
Figure 13
Nakagin Capsule tower
Ramot Housing

The system which was designed by Zvi hecker consisted of hundreds of dodecahedrons sitting tightly one on top of the other, resembling a natural honeycomb. Each face of the dodecahedron was cast from a single pentagonal slab of precast concrete, using prefabricated building technology that was lifted into place by a crane. A concrete skeletal frame formed interstitial voids that functioned as vertical and horizontal circulation between units (Figure 14). (Bergdoll & Christensen, 2008)

System 3

System 3 is the result of a seven year pursuit of low cost, high quality design of a mass produced principle. Proved to be the most sustainable, technologically advanced, flexible, and cost effective model to date. Kaufmann and Ruf’s house is a single unit consisting of a completely prefabricated unit that provides all the “serving” functions called the “serving” space and another space called the “naked” space which is formed by entirely planar prefabricated elements (which could be prefabricated elsewhere with CNC technology): floor slab, walls, windows, optional “skin”, and a roof (Figure 15 & Figure 16). (Bergdoll & Christensen, 2008)
Figure 15 & 16
system 3
Based on the research done on the building systems introduced above, a number of qualities implemented in these systems have been compared and further investigated. In order to define the smart machine for living some specific qualities had to be determined which could introduce smartness in designs. Machines for living basically were designed and presented by Le Corbusier to announce his interpretation in sort of a user centered design – as he believed-. The architect stated “all men have the same needs” and based on this, his attempt was to “design for people” (users) with predictable behaviors and needs, up to this point his ideology was close to what the smart house ideology is. To design for people based on their needs and demands but what makes the new ideology (smart home laboratories) stand out is the definition of for who architects design. The later defines people as consumers but the former define people as users. Today’s smart houses are being designed for People with completely different demands based on their beliefs and perceptions and down to their deepest needs but for Le Corbusier and his machine for living houses were designed for people with the same needs and desires based on their physical features. This in fact was one of the main reasons for its failure. Today smart houses are known for their always online attributes and their futuristic machinery installed in them that makes them really complicated machines, but with different attitude.

In my opinion a house which has been built and designed “smart” is what a smart home should be, not a home with an artificial intelligence which controls the appliances. A smart home is designed to adapt the circumstances to the consumers and allow the customers to apply their preferences in the house but since the automatic machinery can be easily installed in the system after the house has been built, which in fact is how most of the smart houses are being built today, a smart design which enables users to customize or adapt the house to their desires may change how smart houses are being perceived. In the course of reading this book you will eventually be able to understand each one of these qualities.

Most of the projects discussed earlier had a share of smartness in their qualities but to define the ultimate smart machine for living these smart qualities have to be defined exactly, the qualities introduced in the table below have been carefully selected from each project as smart qualities for the smart machine for living.

It can be understood from the table that in time the qualities have improved and a new set of principles have been introduced in the process like customizability, stackability and sustainability. In the chart it can be seen that the last project (system3) is the most advanced of all possessing most of the qualities which makes it the most sustainable, technologically advanced, flexible, and cost effective model among the selected projects.
<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Expandability</th>
<th>Demountability</th>
<th>Quality of design</th>
<th>Plugged-in effect</th>
<th>Cost effectiveness</th>
<th>Customizability</th>
<th>Stackable</th>
<th>Sustainability</th>
<th>Reusable</th>
</tr>
</thead>
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<tr>
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<td>1947-1962</td>
<td>-</td>
<td>-</td>
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<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>?</td>
<td>-</td>
</tr>
<tr>
<td>Habitat ’67</td>
<td>1962-1967</td>
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<td>+</td>
<td>-</td>
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<td>+L</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Nakagin Capsule tower</td>
<td>1965-1968</td>
<td>+</td>
<td>+</td>
<td>+L</td>
<td>+</td>
<td>-</td>
<td>+L</td>
<td>?</td>
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<td>-</td>
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<tr>
<td>Zip-up Enclosures NOS. 1 and 2</td>
<td>1970-1971</td>
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<td>+L</td>
<td>+</td>
<td>+L</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

Table 1 (L = Limited)
When mass-production was faced with customization, a new production method was conceived. Mass customization was born because of the limitations associated with mass-production. Mass customization is the use of special systems and processes to produce custom output for different products. The system combines the low unit costs of mass production processes with the flexibility of individual customization.

Basically it can be translated into the mass production of individually customized goods and services. Therefore mass production and mass customization do not stand opposite to each other since one is complementing the other one. Mass customization is the result of the high volume production and an excellent product mix, where individualized products are expected at the same price as the mass produced items.

James H. Gilmore and B. Joseph Pine II are the founders of Strategic Horizons, a management consulting firm in Cleveland, Ohio. Pine as the author of “Mass Customization: The New Frontier in Business Competition” and Gilmore have defined four approaches to customization called collaborative, adaptive, cosmetic, and transparent which they believe each approach should be examined for possible insights into how best to serve the customers. (Gilmore & Pine II, 1997)

Collaborative customization – based on a dialogue conducted with each individual a product is offered that best serves the customer’s needs. Collaborative customization is appropriate for businesses whose customers could get frustrated when choosing from a plethora of options. In this approach customers are involved in the process from beginning but they will be helped to articulate their needs. (a company called Eye Tailor in the United States has implemented this approach)

Adaptive customization – in this approach customers are offered with one standard, but customizable, product that is designed to be altered by the customers. The simplest example for this approach can be adaptable car seats. (Lutron Electronics Company has applied this approach in their product)

The two other types of customization sit outside the general concept of the customer being in control of the product specification. In cosmetic customization a standard product is presented differently to different customers. Rather than being customized or customizable, the standard offering is packaged specially for each customer.

The last approach described by Pine and Gilmore is the transparent customization. This applies where the company provides individual customers with unique goods or services without letting them know explicitly that those products and services have been customized for them. (Gilmore & Pine II, 1997)

Mass customization
The need for Mass-customization

In cycle of life there has always been a struggle whether it should be the man who had to adapt himself to its environment or the surrounding environment had to adapt itself to the needs of the human. There are some qualities in life which man has no ability to interfere in them or the human power is not enough to change the outcome. Therefore it has been the human that in the sequence evolved to survive the obstacles which he was faced with. Verifying whether adaptation to an environment is considered positive or negative depends on the period of time in which the target man was living in and the aspects of that time he was struggling with. In my opinion human is a selfish being which to an extent would change whatever he can to make the environment adapt rather than adapting himself to the environment. Whether Adaptation is to a house - as a concept - to make it feel like home or to an urban environment in which a person is living in, it is a process and a state of mind that creates a feeling of safety, comfort and security for the occupant.

In the period in which this research was focused on the social housing designed for living to a degree presented an unfavorable adaptation possibility, because architects were deciding the ideal organization of a house based on people’s physical needs rather than their deep perceptions, beliefs and privacies. This I believe was happening in machine age’s social mass produced housing principles in which in people had to adapt to their living environment, however this phenomena was actually unpredictable because of the shortcomings of the period (after two world wars) and the vast need for housing, middle class families had no other choice than to accept the fact that they had to believe in decisions made by the architect for their ideal house, but in time the feeling of that same apartment changing to a ‘home’ was certain although the houses was not built under the occupants preferences. For thousands of years, human evolution has worked to increase our survivability in an extremely hostile environment.

Within the past few centuries, society and technology have advanced to the point where most humans no longer have to struggle to find food or protect themselves from predators. In case of social housing these technologies and the human awareness to their environment allowed them to interfere in the process that effected the ultimate shape of their private domain, as a result today people are not condemned to accept to live in a predesigned apartment or loft and eventually in time be able to call it their home (the feeling), the new mass customization technique will allow them to shape their ideal ‘home’ with the help of CAD technologies by participating in designing their future home, consequently it is possible to assume the feeling could exist before people actually settle down in their new house.

Ultimately in this system houses are adapted to their future occupants before construction phase of the mass produced house.
In conclusion from what that have been discussed throughout this report it is now more clear to vision how to improve the mass produced social housing for a potential smart living which presents a home for the occupants rather than just a house. In certain social and economic circumstances people are obliged to retreat from buying a certain property and invest in a mass-produced social housing unit. I believe the transformation of a house to a home which eventually will happen in time should occur before people move into their new house or at least the process should be accelerated with the help of a certain number of implementations already done to the place to create a feeling of already belonging to the place. These implementations are exactly the ones missing in the machines for living.

A simple rating scheme was applied on the projects in the previous section which is based on a normal aggregation of the scores and an aggregation based on priority of the preferences with descending score multipliers. The scheme proved that in aggregate numbers ‘system3’ was still the most advanced system.

As it is clear in the table none of the projects showed any sign of mass-customization or customizability. The initiative aim of this research was to define a 21th century machine for living consequently it can be proposed that the ultimate machine is the one which can contribute towards producing ‘Quality Affordable Homes’ that corresponds with today’s market demands for housing, affordability and customizability as the general aim, and can be scored more than 8 or 24.5 in the same chart as an ideal high rise mass-produced housing prototype.
<table>
<thead>
<tr>
<th>Name</th>
<th>Year</th>
<th>Mass-customization (6x)</th>
<th>Customizability (5x)</th>
<th>Cost effectiveness (4.5x)</th>
<th>Expandability (4x)</th>
<th>Stackable (3.5x)</th>
<th>Plugged in effect (3x)</th>
<th>Quality of design (2.5x)</th>
<th>Demountability (2x)</th>
<th>Sustainability (1.5x)</th>
<th>Reusable (1x)</th>
<th>Rating</th>
<th>Rating based on priority</th>
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<td>?</td>
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<td>-</td>
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<td>4</td>
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<td>+L</td>
<td>+</td>
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<td>+</td>
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<td>-</td>
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<td>+</td>
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<td>-</td>
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<tr>
<td></td>
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<td>-</td>
<td>+L</td>
<td>+</td>
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<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>7</td>
<td>19</td>
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The Design Concepts
Based on the research done in the previous chapters, it is recognizable that the proposed design is based on prefab housing principle but the typology and the outcome of the design is organized in a way to answer the research question. The concept is shaped to facilitate and enhance the prefab dream which was initialized in the machine architecture period, a mass-produced machine house which introduces a possible living spirit or the state of mind which was lacking in the previous mass-produced projects. The state of mind which in my opinion was associated with most of the projects earlier discussed and was translated into production of low quality container houses that basically contradicts the true purpose of mass production. Producing building fragments in a factory controlled condition should indeed enhance the quality of the product but instead in practice the outcome was the opposite in the mass-produced housing section. In order to re-invent the right state of mind for the customers we should learn from the failures of the preceding visions or try to capture the right essence from each success.

Therefore realizing the design concept started with visualizing the missing properties in the preceding projects formerly studied in the research. The fundamental problem with mass produced projects in my opinion was lack of customer interest. The fact that from 1920’s on, where I initiated my research, a substantial number of mass-produced social houses were developed under economic, social and material limitations after the devastations of the World Wars. The main goal then was to house an extreme number of devastated individuals as fast as possible for the least expense. A replication method was then applied that can be identified as the main problem; monotony in shape and in interior organization was then, and remains now, the repellent factor in choosing social houses. Today mass-customization is replacing mass-production as an agent of change rather than economical repetition. Clients are demanding change –individualization- whether be it a change in the appearance of a building or organizational planning in different stages of the process. The solution here was to apply a method of mass fabrication with return of a custom result to fit the specific customer’s preferences.

If we envisage each house as a unit, a principle for a plain module or off-site fabricated, customizable unit is the ultimate aim of the design, further customizability should be possible in a later stage of the building age. Recyclability and demountability should also be considered as a possible flexibility factor. Flexibility destined for this project has been set to the ultimate level to reach the ultimate housing unit for every taste. Mass customization demands certain user participation in the flow of the design in fact the customer determines what the options will be by participating in the design process from the very start (Kieran & Timberlake, Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction, 2004, p. 111). Depending on the
level of flexibility different types of user participation can be employed, the methods might not be the same but the outcome is. The method chosen for this project will further be explained.

Le Corbusier envisioned the machine for living to be designed with certain characteristics, but the construction limitation of 1920’s was an obstacle for his visionary mind, but this didn’t stop him, one of the ideas of the machine for living was to design the houses in a way they could be built in a high-rise building with the mass-production quality of the machine, he also tried to apply the principle in the UnitÈ d’Habitation in Marseilles, his basic idea for the UnitÈ was to treat each house as an individual prefabricated unit which could be inserted into a support frame just the way a bottle is placed in a wine rack. (Figure 17)

Consequently, since they chose to build the 12 story building in concrete the execution of the wine rack idea was overlooked, but the concept could be seen in the overall look of the building. The idea was referred to as the plug-in effect.

Thus the approach taken for the design process was shaped based on the different visions introduced above yet the challenge was combining these ideas to develop a coherent story that simultaneously possess all these qualities in a logical manner. The assignment was to develop a residential high-rise building with prefab qualities, a housing principle which could be built in any location with generic qualities yet possessing site-specific functions and potentials.

How generic a building is, it should be designed in a manner that it fits in the specific location it is about to be built in, for a high-rise building the site specific characteristics are generally treated in the plinth. Subsequently the building itself consisted of structure, apartments, interior routing and the vertical circulations are designed as a universal building but the plinth and the street level routings are designed specifically for the site. The design however was mainly focused on the flexible apartments and the main structure but the plinth was developed to incorporate a different feeling you would expect from the common high-rise building’s plinth and can be treated as a basic principle which can be applied in other locations as well. A location has been selected in Eindhoven a highly developing city in the Netherlands as a test location for the program, but it still has to be mentioned that here the location is not as important as the generic building itself. Furthermore the design process will be explained along with the general program of the building and their separate locations.
The moment the concept was developed and the research phase of the graduation project was finalized the design phase started by listing the program of requirements as was explained in the introductions. Then the process was begun initially by imagining the machine for living housing unit in a high-rise building. The series of questions that were raised to give order to the process is as following.

How should a machine house be realized in a high-rise building?

Where the process should be started in order to optimize the shape and quality of the building?

What are the prefab qualities of each house?

In the process the building and the apartment units were realized simultaneously to insure the building’s volume matches the units. Primarily a particular attention was paid to the units to get a grab of the possible opportunities. The following story will explain how the building was shaped. Generally the story will follow a big scale to small scale order to help the reader to better understand the process.

The building at this moment was realized as a solid disproportionate tall box. The building’s volume was primarily realized in the process, due to the generic quality of the structure and the building. Residential apartments have also been realized as boxes of 5mx10mx3m for the design initiation stage. Furthermore it is possible to see the primary volume variations in diagrams in the next pages. (Figure 19)

These volumes were designed just to understand the possibilities and to create a line of thought.
Figure 19-20
preliminary design process diagrams
The apartments in the preliminary designs were being realized as container-like units, therefore it was possible to think of them as stackable fragments (Figure 21). Given the possibility it was inevitable not to see the units in different organizations. Detaching unit from each other was one possibility.

Detaching a number of units was an idea implemented in order to create a public space in the gap in the middle. In this way it was likely to see roof gardens or social interactive spaces in the gap. This was only possible because units were imagined to be structurally stable when they are stacked over each other. (Figure 22)

Through detaching units a number of new opportunities were brought to the concept, and creating elevated courtyards in the tower was one of them which had to be further examined.

Detaching units in order to create a social center was introduced but if the units are organized as can be seen in the picture below (Figure 23), the chance to shape an open air courtyard was thin, yet reorganizing the units allowed for a different type of circulation which could comply with the idea of elevated open air courtyard (Figure 24). These courtyards can be used by the residents as semi-private gardens in each center. Diverse activities like barbequing or unofficial meeting can also happen. The range of possible activities is dependent on the climate properties of the season of course. It should also be mentioned that in severe conditions in colder climates, courtyards have to be covered eventually to be able to make use of them.

These certain qualities can be further examined to determine the potential shape and the materials needed for each climate.

Configuring the optimized unit organization to effectively increase the maximum exposure was examined by a series of sun distribution analyses which will be further discussed in the respective chapter on location and site-specific qualities. All things considered, the gap between each pack of units was carefully calculated to maximize the exposure to sunlight and also to minimize undesirable shadow casted on the units located below each other.

**Figure 21**
Stacked Units

**Figure 22**
detached units
Figure 23
Current situation

Figure 24
possible elevated courtyards
Vertical Neighborhood

Generally the building was realized as a vertical neighborhood with separate vertical communities the tower will be designed to present the different zones that would normally spread out within a neighborhood in a city block. Usually when a neighborhood block in an urban situation is being designed it will include residential spaces which are connected to each other by a neighborhood center. A neighborhood center could include a green space, a social space or a market. In high-rise buildings because of land limitations the social element cannot be seen therefore the typology of an urban block cannot be compared with or be included a high-rise building. In the proposed project a different typology for the high rise is being implemented that by detaching units, each part containing several other small units is treated as a separate neighborhood claiming its own social center(s). It is also imagined to place social connector spaces on each level to be used by the owners of that specific level to increase the lack of sociability that can be seen in the typical residential high-rise building. (Figure 25)

The first step towards prefabrication

Another opportunity which was brought to the concept from detachable unit’s idea was the chance to presumably enabling units to be removed from a conjoined pack. Meaning it might be useful to be able remove or replace a certain unit for a further modification or interior rearrangement in the future. If it was possible to implement such an idea in a high rise building it could be a significant contribution to the flexibility section of the project’s conceptual theory. In this manner units can be built in another location or maybe in a factory under controlled conditions with prefab qualities that are the main pursuit of this project and then be moved to the site and be attached next to the other units. Additionally if a certain unit could be removed after the building was constructed, numerous modifications could be done to the unit to provide users with new opportunities in a unit’s lifespan. (Figure 26)
The first step towards prefabrication

Figure 25
vertical neighborhood

Figure 26
Removable Units
Social connectors

Social connectors which have been placed on each level are imagined to be constructed with the same method as the units but the only difference is that they are treated as permanent—fixed—volumes, but in a demanding situation they can also be removed to be placed in another location, for instance if an adjacent unit was to be expanded and the owner was willing to compensate the costs, the permanent social connector can be slid—not literally slid—-one unit to its right or left but not to be removed completely. (Figure 27)

The function of the social connectors are yet to be selected by the residents of each floor in a unanimous decision from a number of various programs from library, kindergarten, garden, café, bar, sitting area, meeting room to anything based on user demand.

It has been considered that modular units in this proposal are removable, replaceable and expandable; the exact method implemented for the proposed idea will be described further in the process.

Since this project is a user-centered design, each variation of the volume or the program in general has been modified to increase the individual comfort level, whether in flexibility aspect of the building or the climate-comfort of the building. Therefore the idea was to keep the vertical circulations and traffic corridors in a situation in which none of these two were blocking or limiting the desirable solar exposure intended to reach each apartment. The building should also be oriented toward the best possible direction which varies for different locations—this will be specifically determined for the location it is meant to be built in-. Basically the corridors and all the structural cores containing circulation will be located on the north or on the sides to leave the south side for the potential apartments. (Figure 28&Figure 29)
Figure 27
Permanent Units

Figure 28
two different volume variations
Configuring Structural Cores and Circulation Routes

Considering the explained unit qualities, specific structural decisions had to be developed to incorporate the plug-in effect. To execute a steady and practical structure various possibilities had to be examined. Eventually it was decided to shape the building around solid structural cores (Figure 29). Structural concrete core(s) acting as the main structural element of the high-rise which also included the vertical circulation throughout the building. At this point in the process the quantity and the exact location of these cores were not yet decided, but accordingly the optimized number and position was determined after further development of the project.

Consequently it was realized that for structurally supporting units another structural element had to be complementing the supposed cores in order to keep the proportion and number of the cores as small as possible. The additional structural element could not be anything else than the corridors. Suspended corridors reinforced to bear the load of a certain number of units that are only connected to the cores on their sides or only in certain points. The combination of these connections will create a coherent structural stability that will indorse and enable the units to be modified, removed or replaced. (Figure 30)

Up to this point corridors, while being connected to structural cores, have been placed distinctly on one side and units on the other. Based on the determined location of the corridors three main cores have been designed to structurally transfer the loads to the ground and also comply with the previously explained concepts (Figure 31). These main cores include the main staircases, elevators, emergency fire exits and mechanical installation. The number of cores has been kept to the minimum. Beside these three main cores two additional mini cores have been complementarily planned that besides having structural properties, like a mega column, contain ducts for mechanical and electrical installations. (Figure 32)
Figure 30
structurally reinforced corridors

Figure 31
structural cores

Figure 32
mega columns configurations
Routing and Social Sustainability

As was briefly explained before, a particular type of circulation has been implemented in the project. A different typology of high-rise residential building has been implemented to improve social sustainability and also a particular type of vertical circulation throughout the structure is designed for faster and yet more sociable transportation.

The routs in the building have been designed not only to accommodate a vertical transportation but also it has been tried to bring social interactive routs to the building. Social sustainability has been defined by the Young Foundation as follows:

“A process for creating sustainable, successful places that promote wellbeing, by understanding what people need from the places they live and work. Social sustainability combines design of the physical realm with design of the social world – infrastructure to support social and cultural life, social amenities, and systems for citizen engagement and space for people and places to evolve” (Woodcraft, Hackett, & Caistor-Arendar, July 2011)

It translates into how connected residents feel they are or the sense of place in the community; the access to services; green design features; cultural activities and community involvement.

“Social and cultural factors are identified as an essential element because of the contribution they make to building vibrant and inclusive communities. Six areas are identified as important supports for social and cultural life: a sense of community identity and belonging; tolerance, respect and engagement with people from different cultures, background and beliefs; friendly, co-operative and helpful behavior in neighborhoods; opportunities for cultural, leisure, community, sport and other activities; low levels of crime and anti-social behavior with visible, effective and community-friendly policing; and opportunities for all people to be socially included and have similar life opportunities.” (Woodcraft, Hackett, & Caistor-Arendar, July 2011)

Therefore Two main elevators there have been placed in the center of the tower to only transfer residents from the ground level to each neighborhood center and from there based on the floor layout and the destination another elevator will take the users to their house. What happens in the centers is associated to improve social sustainability, because channeling through these centers will impact on how people are connected to each other and provide a sensible meaning to the whole idea of getting engaged in a community. The tower’s routing has been imagined to be like routing in an urban block with diverse streets and different direction possibilities to let the residents choose how they would want to get from one place to another. But generally the main focus is to make the centers appear more dominant than the rest of the neighborhood in each segment of the building.
What typically happens is that an elevator takes the resident to their intended floor while the elevator stops in each and every level. This will make the travel time-consuming. What that has been done in high-rise buildings to improve this problem was to increase the number of elevators while assigning each elevator to a certain levels-even/odd- but this method is still not efficient (Figure 33). The main elevators in the proposed building are to be assigned to have stops only in a limited number of levels; potential parking levels, ground level, neighborhood center 1&2, central communal level and a potential recreational level on top. The other elevators are distributed to facilitate access to a limited number of levels. (Figure 34)

Directing a guest to one’s house in the building is much like how the guest would be guided through a city, thus the building’s postal address is not enough to guide the guest to the front door; a complementary in-building address should also be provided to direct the guest to the front door. This address should be self-explanatory enough to let any individual find the way through the building. (Figure 35)
Figure 33
Typical circulation
Figure 34
Routing layout
Proposed customizable unit

During the conceptual design process the fundamental design ideas for the intended customizable house were identified and were explained thoroughly. One of the main criteria’s that had to be reached beside mass-productiveness was customizability.

Primarily the level and type of customization had to be determined in order to recognize obstacles and the problems that might occur during the process. Personally it is believed if a product is truly customizable it has to be modifiable in every aspect without a limit. Different types of mass-customization were identified in the research. It is noticeable in adaptive customization that the definition of customizability is variable since a product can be modified only before or before and after delivery. For instance in car industries the interior of the car is customized based on the customers preferences before it is being built but these chosen properties are irreversible and unchangeable after the car was built. The same happens for the color and the type of engine installed in the car. Today a lot of customizable products can be found like laptops, clothing, phone cases, sunglasses and etc. but the post-production customizable products are rarely found and if found only provide a limited range of customizability. In housing industry the customization spectrum is limited to providing choices to the customers in the design process and not in the post construction stage. An adaptable house is another term in customizability which will allow for further modification in the house but it is believed that movable walls and furniture is not a true solution to the definition of adaptable customization because the support section of the house is still constant and a slight portion of the infill is adaptable to user’s needs.

Finding a true customizable housing principle is the main objective of this research. Therefore the limitations and obstacles will be defined first and then the potential method will be discussed.

Defined obstacles

Providing customizability in housing industry is not the same as other industries because the cost of customization in housing is incomparable to customizability in electronic or clothing products. Therefore a combination of two types of mass-customization could be advantageous. In this project the combination of collaborative and adaptive customization is chosen in which customers could participate in designing their apartment—by engaging in a multiple choice questionnaire—and also the components are standardized to provide users with modifiable systems. A list of potential customization possibilities will be provided and then problems associated with the future modifications will be discussed.

- Wall positions
- Kitchen and bathroom position

Figure 36
different floor types
- Modifiable mechanical systems

- Expandable apartment

- Component based modifications (doors, windows, kitchen cabinets, etc.)

- And generally the interior arrangement

All of the above mentioned modifications require a particular structural system that allows for disassembling and reassembling the components from each other. Particularly the major problem is with the plumbing and mechanical systems which include water piping and waste water removal accessories. If the problem with plumbing could be resolved, finding a solution for other modifications can be followed. The other major challenge is removable floors. The dimensions of floors also have to be optimized for transferring them to the site and also placing them in the allocated floor level. Also the units have to be designed in such a way that permits removing them from a series of other connected units.

**Method**

If houses were designed with a technique that would allow them to be disassembled this could introduce a modifiable and adaptable resolution to the principle. In order to find the best possible solution the method has been practiced by primarily looking into floors and their dimensions. It should be noticed that Components should be small enough to be carried by a normal truck and the non-structural parts have to be light enough to be removed or replaced without the need for a crane. Transferring a floor with dimensions of 5x10 is theoretically either impossible or very difficult. Consequently each floor has been divided to 8 separate 2.5x2.5 floor element to introduce a movable floor component.

Plumbing pipes could be included in the floors as a factory made product but to cover all possible piping routs in a house several types of floors have to be produced which is inefficient, since plenty of them might not ever be used in the process (Figure 36).

An efficient way might be to think of floors with potential empty spaces in the middle to allow for unlimited types of plumbing. To support such an idea the empty spaces in each floor was designed so that three outlets of pipes can be placed on each side (Figure 37). Hence the floors should be made in two or three removable parts which are structurally supporting each other and also provide reasonable offsets for structural walls. All the following diagrams are conceptual diagrams and they do not express the shape or the material used in the final stage.

![Figure 37](empty_plumbing_spaces)
Figure 38
Floors in two parts

Figure 39
Floors in three parts

Figure 40
The proposed idea for floors
If any of the components introduced above were built in concrete or any type of solid material their transportation would be problematic for the users, this problem resulted in a need for more in-depth research on the materials used in the project. The following case studies were an inspiration for choosing aluminum profiles for the structural properties.
Based on the conceptual demands of the project, a number of cases have been studied to find the best possible structural approach for designing the prefabricated units mentioned previously. The case studies discussed below were selected for their novel approach in prefabricated architecture and also for their exceptional choice of materials. Both Loblolly house and the Cellophane house were the pioneering prototypes of a visionary architectural concept presented by Stephen Kieran and James Timberlake.

Prefab structures

Loblolly House

The loblolly house was the first implementation of the ideas described in the book ‘Refabricating architecture: How Manufacturing Methodologies are Poised to Transform Building Construction’, from the architects Stephen Kieran and James Timberlake. In which the authors have focused on prefabricated buildings by comparing it to cars, airplanes and ship manufacturing industry. The authors discussed the various reasons why prefabrication construction has failed and people don’t like to live in prefabricated houses. An effort has been made by the indicated architects to change the common perception of prefabricated architecture by explaining how the materials used in architecture are unchanged from 15th century and the focus should be on invention and implementation of new materials. (Kieran & Timberlake, Refabricating Architecture: How Manufacturing Methodologies are Poised to Transform Building Construction, 2004)

Contrary to the usual construction methods it was decided to take an off-site factory based production for the house. The construction method implemented in the loblolly house was of novelty, the more efficient way of building through the use of building information modeling (BIM). Generally the building is interpreted into a 3D model which contains all the construction aspects of the building that is needed from structural dimensions or architectural arrangements to intricate details of each and every corner of the house. The house was partially manufactured off-site and placed over the foundation. The house was built from a few numbers of components which were assembled in the
factory from a thousand other parts – the fragments and parts aspect that has been explained earlier which originally stemmed from the car and airplane industry. Every aspect of the building have been designed and tested before the construction was actually started to prevent any undesired circumstances.

Scaffolds are temporarily used to provide elevated work platforms in construction but in the Loblolly house it is used differently. The scaffold here is the main structural element of the house and is composed of two elements: extruded aluminum profiles and basic connectors. The scaffold forms a base for the factory built components to be attached to. Aluminum profiles were selected from standard profiles from a manufacturer’s catalog which were originally designed to support industrial manufacturing elements. (Kieran & Timberlake, Loblolly House: elements of a new architecture, 2008)

The qualities that motivated the architects to use the aluminum profiles for their architectural advantages were its ease of use and speed of assembly as well as availability and flexibility.

All the amenities necessary to make the house habitable were embedded in wooden cartridges which formed floors and ceilings. These cartridges were simply attached to the aluminum frame structure.
Figure 43 - 43.1
Different connections in Loblolly house
Cellophane House

Cellophane House is a five-story temporary dwelling made of transparent, recyclable materials that demonstrates an all-inclusive approach to off-site fabrication. The structure is a scaffold for holding materials together to create an inhabitable space. A bolt-together aluminum frame provides the structure and the means to attach customizable, factory made elements together with connections that allow for further disassembly. When it is no longer needed, the house can be disassembled, and the materials moved, reused or recycled, helping to reduce the millions of tons of construction and demolition remains generated in the United States each year. (Figure 44) (Figure 45)

The house was located in New York City for a three-month exhibition in 2008 about the history of prefabricated architecture. At the end of the exhibition the house was disassembled and is currently awaiting for relocation.

Aluminum framing/Materialization

Aluminum profile used in the previously mentioned projects have been selected from Rexroth aluminum structural framing products range which offers a wide range of profiles, connectors and accessories. Their unique design is believed to be specially engineered to provide high strength-to-weight ratios. The above-mentioned architects have chosen the aluminum extruded profile from this company since it has enabled them to develop a system of off-site fabricated building. These profiles complemented their idea of building a prefab model of housing which contributed to their sustainable strategy. A house which could be assembled on site, dismantled and reused in future. Using aluminum extruded profiles for a temporarily held assembly allowed them to show their contradiction to the conventional method of permanently fixed construction.

Figure 44
Cellophane House, an interior view

Figure 45
Cellophane House, an exterior view
Figure 46
Simple Aluminum profile connection

Figure 47
90-Serie profile Cross section
The Unit

Based on the inspirational works introduced above and the materials used in them, the frame work needed for the units in the project were designed based on the same extruded aluminum profiles from the projects. The unit’s structure is design with the conceptual arrangements explained in the method’s chapter, but only the bottom layer used in the design has structural properties (Figure 48). The empty layer and the floor are not structural. Aluminum profiles are connected to each other by the means of custom fabricated L-shaped connectors, because the scaffold system was not designed with structural loads in mind therefore another structural element had to be used in the system (Figure 49). The unit’s structural frame has been designed to transfer loads to the structural corridors. Units are connected to corridors from only one side and are designed to be cantilevering from the corridors (Figure 50). Units are no longer directly standing over each other they are cantilevering from the corridors. A gap of ten centimeters is separating units from each other on each side (Figure 51). This gap has to be maintained in all situations. Units and their components have been reinforced to bear the live and dead loads and the aluminum profiles have been structurally calculated to check if they can endure the 10 meter cantilever.
Because of this standardized method, units can be connected to one another to create completely different variations of unit combinations (Figure 52). This will contribute to various user preferences and decisions. It can be seen that the number of possible combinations are unlimited (Figure 53). Generally the combinations are made from a standard unit.

Each floor part has been designed to be built with standardized profile sizes. Based on the position, each part’s type is different. Whether it is located on the corner, the middle or if a column is included in the part the sizes are different (Figure 54). Different types vary in their arrangement and the only dimension difference can be noticeable when a column is placed on a corner. Floor profile’s connections rely on dry joints with simple bar and plate elements (Figure 56). A particular type of dry joints has been acquired to prevent adjoining horizontal members from separating (Figure 55). Generally everything is assembled by the means of bolts and pins.
Figure 52
Unit standards

Figure 53
Never-ending unit combination possibilities

Figure 54
Different floor types

Figure 55
Dry joints

Figure 56
Coated metal plates located above and under the joining floor parts
Another type of connector, supports the beams and columns not only protect the entire aluminum frame against major lateral forces but also is the main structural element supporting the cantilevering floors and ceilings. These diagonal braces support the frame and provide resistance against forces imposed by shear pressure on the corners. These custom fabricated connectors are built from simple diagonal cables which fasten corners at structurally demanding corners. (Figure 57)

The other custom fabricated connection is the Z-shaped element (Figure 58) supporting the floors to be positioned 15 centimeters above the structure for mechanical ducts under the floor for the plumbing (Figure 59).

Floors are designed in two parts, a fixed part in the borders and a removable part in the middle. The removable part has been realized to allow for further modifications in plumbing (Figure 60).

The following diagrams will display the construction process behind building each unit.

The type of materials used in the unit will be explained in the materialization chapter in the design document’s section of the book.

Further modification possibilities

Each unit in this project has been designed to allow for further modifications in the household, which lets the customers modify their apartment based on different circumstances they are in, but based on their intended modification and its level the required method of applying that modification is different. The levels of modification have been defined in the project with two levels, minor modifications and major modifications. Minor modifications are the ones that applying the change in the house do not require the unit to be completely removed from the structure, and those changes can be done in place but for applying the major modifications the intended unit has to be removed and be transferred to the off-site workshop with the help of the stationary crane on the building.

The following list indicated the exact minor and major modifications that has to be considered for applying further customization on each unit.

Minor modifications:
- Changing interior walls
- Changing kitchen/bath/toilet position
- Joining two units above each other
- Changing façade
- Changing finishes
- Adding a Balcony

Major Modifications
- Expanding unit to either side
- Joining two adjacent units
- Changing function from living space to a garden

Figure 57
Diagonal Bracings
Figure 58
Prefabricated Z-shaped connector

Figure 59
Prefabricated Floor Segment which is transferred to site for assembly

Floor supporting elements

Figure 60
Prefabricated Z-shaped connector

Floor elements
Structure and construction (The prefab unit)
1. Insulated Metal Panel
2. Plywood Floor and Ceiling
3. Diagonal Bracing
4. Wooden strips surrounding balcony
5. Aluminum Frame
Site-Specific Design Process
Site-Specific Design Process

The most crucial part in a design process is identifying the relation between the design and its surrounding. Buildings should be positioned in such a way that leads to a coherent connection with urban environment. A number of elements are influential in the way buildings are shaped in an urban scale. Urban design is the process of designing and shaping cities aimed to make connections between people and places, movement and urban form, nature and the built fabric (Urbandesign.org). Buildings’ design can also contribute to making connections and movement in the urban scale. Different architectural design decisions can revitalize an urban space, specifically for a high-rise building with limited ground level space.

Previously the generic qualities of the project was described, specifically the shape of the volume and units were formed during the process. In order to check the feasibility of a prefab based project it is better to place the building in a real situation and define how the building is connected to surrounding streets. If the units in this project were to be placed in a site independently of another structure then the need for introducing a specific site was unnecessary but since the units are being introduce in a high rise building considering building correspondence to the surrounding environment is crucial. This section of the book is generally concerned with defining a certain location and explaining ground level routing and solutions for the plinth.

Location

Since the project has been designed in prefab principles it should be possible to place it in any location but defining a certain location could be beneficial to the research and introduction of a ground level plinth for the high-rise housing building. Therefore based on ease of access and availability of location data it was decided to pursue finding a location in one of the highly developing cities in the Netherlands, Eindhoven.

Why Eindhoven

Eindhoven is a city located in the province of North Brabant in the south of the Netherlands. The city had 218,559 inhabitants (November 2012) and 261,082 if adjacent Veldhoven is included, making it the fifth-largest city of the Netherlands and the largest of North Brabant. Eindhoven was named world’s most intelligent community by Intelligent Community Forum. Eindhoven is the host to a number of the leading technical companies in the Europe and the birth place of the electronics giant Philips. The city has been constantly growing from the industrial revolution and still is. The city center hosts a number of high-rise buildings. The concentration of the high-rise is in the city center but the secondary city center (wonsel centrum) is also growing in the number of

Figure 62
Proposed urban strategy
high-rise. A number of locations have been proposed for future high-rise developments in the prospective urban strategy. (Figure 61)

Skyline analysis

The following analysis has been conducted to examine another influential aspect of high-rise buildings. High-rise buildings are the element displaying a city’s skyline. Skylines are the urban signature or the fingerprints that define a city’s identity and its symbol. Photography and mass media have displayed the image of tall buildings portraying a city’s skyline as an aesthetic product to be admired as a strong symbol of the city. Ideally speaking, building heights should be well ordered in a gradual sequence, varying from the least to the greatest height to create a visually appealing skyline. This does not often happen because of various reasons from height zoning regulations to financial reasons. Diversity in building height should be considered to avoid uniformity and a flat skyline. High-rise structures should be treated in a whole and not as isolated objects. (Al-Kodmany & Ali, 2013)

Integrating a tall building into a city within an existing infrastructure is difficult and complicated, a series of vantage points have to be taken into account. In practice it is impossible to guarantee a definitely desirable visual impact from all vantage points. Therefore focus should be placed on most common views, such as views from major roads, side-walks, railways, and major open space (Al-Kodmany & Ali, 2013).

Shaping a coherent skyline without gaps in between the key tall buildings will contribute to a more visually desirable and less disruptive harmony of a city’s skyline.

Consequently in order to successfully integrate a new high-rise building in Eindhoven the city’s skyline have been produced based on two main vantage points, these vantage points are looking to the city from the 2 most popular roads leading to the city. Based on this analysis the prospective location will be identified.

The diagram in the next page shows the exact locations of all tall buildings in Eindhoven which are above 50 meters.
All the high rise building in Eindhoven above 50 meters

Legend
- Orange: 50m-55m
- Blue: 55m-65m
- Green: 65m-80m
- Red: over 80m
After modeling the skylines views (Figure 64) (Figure 65) they have been examined for locating possible site locations to improve the overall city skyline. In order to find the location it was decided locate a site in which the future building could fill a gap in both skylines.

The overlap from two major gaps in the southern and four gaps in the western skyline determined 8 possible locations (Figure 66). The most effective site for a future high-rise was then chosen. The proposed site is located in the most concentrated area with the tallest buildings around.
Figure 64
Conceptual skyline

Figure 65
Skyline view from southern vantage point

Figure 66
Skyline view from western vantage point
Figure 67
Eight possible location
The site

The proposed site is located in Eindhoven’s city center which is situated in the southwest of the central shopping area (Figure 67). The most important streets in this area are the Kleine berg, Grote berg and Bergstraat. The district is characterized by the various (dining) cafés and artistic art and antique shop and it is one of the oldest neighborhoods of Eindhoven and largely spared during the war. The district has many characteristic houses and streets. The tallest buildings in the area are de Admirant, de Regent and the Hooghuis building. This site currently functions as a public parking with 85 parking spaces and a luxury cuisine. These functions will be included in the future building to compensate their loss.

The main streets leading to the site from the retail center are vrijstraat and hooghuisstraat. Vrijstraat is the main street leading to kleine berg therefore it is being widely used as the main access street to/from the center to kleine berg. Although hooghuisstraat has the same connection to the indicated street it has been slightly abandoned comparing to vrijstraat.

The main street crossing the site is Keizersgracht Street that can provide automobile access to the site (indicated in the map with a black arrow).

Urban qualities/potentials

The proposed site has the potential to completely revitalize the area by introducing a new access route to Kleine Berg. Since it is located in one of the densest areas in the city it can provide residents with houses in which are neighboring a vital district of the city and are nearby urban facilities. Main access roads are conveniently reachable by car. Eindhoven’s train station is reachable by public transportation and is located within walking distance. Retail shops and grocery stores are located adjacent to the building.
Ground floor volume

The Plinth

The main idea behind designing the plinth was to contribute to the city’s urban environment as much as possible unlike the typical high rise structures which add a little to the surrounding street life and are better known for shaping skylines. The primary idea is to design a plinth which integrates urban public space in the building instead of being identified as an isolated volume intended only for the residents and the users. In order to do so the plinth was designed in three levels. The one below the ground is intended only for the residents and is located one and a half meters below the ground which is connected to the street by a gentle ramp. The two other levels are public spaces generally connecting the two separated urban blocks located on the north-east and south-west of the site together. (Figure 68)

Floor layouts

Generally speaking the second level is designed as an extension route connecting Hooghuisstraat to Kleine Berg street by a ramp on the both sides which at its highest level is located at 1.5 meters above the ground. This rout is designed exactly as wide as Hooghuisstraat’s width to merge itself to the urban network as a normal rout (Figure 70). The main reason behind designing this rout was to revitalize hooghuisstraat and to become a point of interest for people to choose this rout over vrijstraat which in the current situation is the main access to kleine Berg street.

An indoor bar is placed in the second level. The idea behind including a bar/restaurant in the plinth at second level was to shape the same activities happening in Kleine Berg (bars, restaurants, boutiques, vintage shops) along this extension as an invitation to the popular Kleine Berg street. The third level which has been elevated 6.50 meters above the ground is identified as an elevated open public garden, which includes an open air restaurant/bar provided by the restaurant designed in the ground and second level.
Figure 70
Current access route to Kleine Berg street

Figure 71
The extension route connecting Hooghuisstraat to Kleine Berg through the plinth
Figure 72
The ramp going through the building
Figure 73
Elevated open public garden
Arrangement of activities

The residential area of the building is accessible from the level which is located 1.5 meters below the ground with a gentle ramp from the main entrance. This level is generally dedicated to the residents and not the public; the only accessible part of this level is the entrance to the restaurant that is located on the ground level. The level has been addressed in a way which at first glance shows no particular sign of a root or an access to the other part of the building, this has been achieved by blocking the line of sight from outside, but in reality and from close range it is connected to the other side which has been thought to be a private garden for the residents. A bicycle shed has been designed in this level for the guests and also a required number of post boxes have been located in the front of the residential entrance.

Other activities in the building have been explained partially in the previous chapters. The diagrams will display how programs are arranged through the building.
All the units have been placed in the building to receive the maximum amount of sunlight to increase the comfort level of the units. Since this project was being realized in the Netherlands and due to extreme climate in the area, it was important to orient units to the side in which is affected more to the sunlight. Therefore it has been decided to choose the south side of the location for the units to be facing to. An intricate analysis has been carried out for the sun distribution and sun’s altitude for the city of Eindhoven to realize the best possible location and orientation of the houses and also to find an altitude range in which sun can penetrate an opening in the building in the worst months of the year to reduce shadow casting and to let sun light in the plinth. The analysis is however irrelevant to the content of the book but the result can be seen in the visualized image below from the plinth in the lower level of the building. the angles that have been used to cut the building are identical for each location because they are based on the lowest (21 December) and the medium (21 September/ 21 March) height –altitude- of the sun for that particular location.

Unit Orientations based on Sun Distribution
Figure 75
Entrance to the plinth and the residential area

Figure 76
Cutting angles in the plinth
The building as has been explained before is built based on structural properties which have been designed to carry detachable units’ load. Units are connected to the main structure only on one side hence the corridors are the main load bearing structure for units. Each corridor in the building has been placed in the structure to be held by the primary and the secondary cores in the building. Primary cores are the ones containing vertical circulations which are located on the sides and the middle (Figure 75) while the secondary cores which are only designed as mega columns with only contain service ducts are located on the other sides. (Figure 76)

All the cores are steel structures encased in reinforced concrete. The main cores located on the sides are designed with openings to enable a better illumination quality; openings are structurally connected to the solid concrete with the means of cross braces. The columns are built with 40x40 dimensions to structurally tolerate and transfer the loads to the ground. All the columns in the cores have been designed with standard dimensions to reduce the number of column variations. Columns are eventually designed to get slender in height to reduce their weight gradually. All the beams in the cores have been designed in a standard manner to correspond to the previous concept. The two cores located on the side are identical in their size and function. The core located in the middle which is the most important structural core in the building is accompanied by a mini core (mega column). The main core includes fire escape routes and the main two elevator shafts. Since these elevators only have six exits in the whole building, this could be a great contribution to the structure since the number of openings has been kept to minimum. (Figure 77)

Cores are structurally connected to each other with corridors; two types of corridors have been introduced because of the two different unit orientations, both types of corridors are adjoining the whole structure together as a belt. Corridors have been structurally designed with steel structure that is shaped like a cage, additional diagonal braces have been included in the corridors to transfer lateral loads to cores and support the cantilevering parts. All the columns and beams in the corridors have been adjusted to a standard size. The number of varied standardized columns and beam in the structure has been kept to the minimum to the point that all the different types can be printed in one page.

All the steel elements in the building are assembled using steel bolts without welding.

The centers in each neighborhood are also built with steel structure which also acts as basic adjoining elements in the structure since they are designed to be connected to all the cores unlike corridors which leave one core unattached in each type.

Figure 77
Primary cores

Figure 78
Secondary cores (Mini Cores)
Figure 79
Striped structure

Figure 80
Steel structure enclosed with reinforced concrete
Figure 81
Corridor’s structure
The diagram illustrates the structure without the units attached to it.

Figure 83
Building’s structure with detached units
Figure 82
Neighborhood Centers
In a process where the signs of public participation are the least, citizens are only just involved in a later stage of the process. By the time they will be involved, decisions have already been made and citizens are only asked about their opinion on the decision but even though they have been asked about their opinions since the major decisions have already been made, plans or designs might slightly be changed. In a complete case of participation, people get involved in a much earlier stage of the process and they will be invited to think along or actively participate on a certain question in an early stage. (Driessen, 2011)

Different methods of public participation have been implemented in the design spectrum, the method introduced in this project has a different approach to the design in participant’s way of applying his or her perception and also the way they are confronted with the materials.

**Proposed method of participation**

In the method introduced for this project the users are free to decide where and how they want their spaces organized in their future house. But the process is initialized way before the public participation has started. Since the units have the potential to be modified in any situation, this allows for different positions for household spaces that require piping like kitchens and bathrooms, therefore everything in the interior organization is possible. Users can decide where they would want their kitchen to be placed or their rooms and so on. This will allow for unlimited types of floor plans in different numbers of units.

Users have two choices for designing their future residence, first is to pick a floor plan from a catalog of pre-designed floor plans designed by the architect. The second choice is to start from scratch and place everything in their units as they are pleased.

Generally the process starts with a nine question questionnaire which defines the effective number of units which have to be combined to shape the apartment and can also identify some important living qualities that affects the interior organization significantly similar to the number of rooms, location of the master bedroom, size and position of a private garden and so on. This questionnaire can be done individually without the presence of the architect and can also be done virtually in an online space. By answering each question from the questionnaire a number of pre-designed floor plans from the catalog will be omitted since they do not comply with the preferences of the user. By the end of the questionnaire the client can decide if he/she wants to choose an apartment from the catalog and modify the plan or he/she would prefer to start designing from scratch. Since the client has already filled the questionnaire the number of units they need for their future apartment is defined and they only have to decide on the floor plan. The questionnaire can be found in the appendix.
Designing a floor plan can be frustrating for some without the presence of an architect and can be hard for them to realize what to do and what not to do and also changing the position of a space can be durable, that is why in the proposed plan the client is involved in scaling or moving furnished spaces rather than walls and doors, in the process each space is shaped similar to a colored square that can easily be moved and be identified as an individual space but without doors, walls and windows in the plan. This can be called the first stage in the process. The modification of the spaces should be as easy as moving icons in an android or iPhone smartphone with a drag and move action.

In the next step the architect steps in and checks the proposed plan designed by the client for authenticity and the general organization of spaces. If any changes had to be done the architect will apply it. He will also determine the best position for the doors windows and the garden. The plan in this point will be sent back to the client for the final confirmation. If they agree with the plan it will be sent to the factory for the main parts to be determined and built.

**Test case: target group A&B**

In order to test the proposed participation method two groups of my colleges have been volunteered to participate in the process of designing their own house. The first group are architects and the second group are mostly engineers from different majors. They are all in the same age group and not married but two couples are in the group that have been asked to design the house individually but for a future house for them both. They have all been asked not to worry about the cost of the house and to concentrate more on what result they want from the process.

These test groups have been chosen to pinpoint how a non-architect would participate in the process and if they would achieve the same result as the architects. This method of participation has been particularly designed to simplify the process to understand how people would react to what they have been faced with in designing their house. The architect did not have any interference in the process and the target groups have designed their house on their own.

A number of nine questions have been given to each individual to identify what they want. Each question have been asked to identify a certain point for the unit, number of needed units, location of each unit, and the questions are mostly qualitative not quantitative.

**Results**

The list of the questions and the results from this test case can be found in the Appendices.
Conclusions from test cases

Generally the method was considered to be entertaining for the participant since they could easily recognize the colors and play with them while choosing the location and the dimensions of each household fragment. Realizing that the pieces were simple to understand and without any common complicated drawing details helped the participant to design their house without thinking of where the walls, doors, ducts, pipe lines would be located. Therefore it can be understood from the test cases that using colored pieces without walls can be beneficial for the method but the main issue recognized by the participants was the papers itself which was applied for the participatory design. They have reported that instead of colored papers the method should have been applied in a computer visualized application which they could interact with it on a pc but this was unreachable for this research to conduct such an experiment that is why this method have been used at the first place.

As a conclusion it should be considered that using simple methods of demonstrating the participatory design with colored spaces instead of the commonly used complicated methods which demand the participant to customize a house by moving walls, doors and furniture is preferred by the customers since they are interacting with the whole space not the details of that space.

Overview changes to be made

The major change to be applied in the participatory design process is the way it should be presented to the customer which should be in an interactive computer application which could be applied over different platforms. Android and iOS devices could be a great contribution to this method because then people can take part in designing their own house in the comfort of their mobile phones or tablets without the need for any supervision.

A Possible Scenario

Here you can find a possible completely different scenario for a family of five who decided to buy an apartment in the building.

The hypothetical scenario for a family of five which the mother works at home as a therapist, the father is an engineer they have two sons 15 and 13 years old and also a daughter which is ten years old.

The family has been imagined to be an upper middle class family and have decided to buy an apartment in the building. The father has demanded a private garden and the mother is in need of a home office which has an independent door to the outside. They would also want a second entrance for the kids for if they wanted to bring friends over so they wouldn’t disturb the parents. Parents have also asked for an
isolated master bedroom with private bath and a separate walk in closet.

In order to demonstrate how customizable the units are, it has been decided to show how this family can re-arrange their house after a period of ten years. After this period all the children have moved out and the middle son have gotten married and have decided to live in the same building close to the parents.

The following plans can demonstrate how the units have been arranged to fulfill this family’s demands in a period of ten years.
The family’s house designed when they moved in
The family's house re-organized after 10 years
Design documents
Ground Floor plan (at -1.50m)
Second Floor Plan (at +7.00m)
Type A Floor Plan Possibilities

These floor plans have been designed to demonstrate the possibilities in designing housing units and not the end product.
Type B Floor Plan Possibilities

These floor plans have been designed to demonstrate the possibilities in designing housing units and not the end product.
Skylobby Floor Plan level one (at +70.10m)

Skylobby Floor Plan level two (at +74.66m)
Sky Gym Floor Plan (at +124.10m)

Sky Lounge Floor Plan (at +129.20m)
1st Basement Floor Plan (at -4.50m)

This parking level is intended for public use only to compensate for the public parking currently functioning in the site.
2nd and 3rd Basement Floor Plan (at -7.50m & -10.50m)

*This parking level is intended for local residents use only*
a View from the first neighborhood center
Interior view to the outside
Expected corridors
Details

Wall Section  Scale 1:200
Standard unit Section  Scale 1:100

Standard unit Section (including balcony)  Scale 1:100

Detailed Unit plan  Scale 1:100
Detail 2 in 3d
In order to define the smart machine for living some specific qualities had to be determined, the qualities which could introduce smartness in designs. Machines for living basically were designed and presented by Le Corbusier to announce his interpretation in sort of a user centered design – as he believed-. The architect stated “all men have the same needs” and based on this, his attempt was to “design for people” (users) with predictable behaviors and needs, up to this point his ideology was close to what the smart house ideology is, To design for people based on their needs and demands but what makes the new ideology (smart home laboratories) stand out is the definition of “for who” architects design. The later defines people as consumers but the former define people as users. Today’s smart houses are being designed for People with completely different demands based on their beliefs and perceptions and down to their deepest needs and desires but for Le Corbusier and his machine for living houses were designed for people with the same needs and desires based on their physical features. This in fact was one of the main reasons for its failure. Today smart houses are known for their always online attributes and their futuristic machinery installed in them that makes them really complicated machines, but with different attitude.

In my opinion a house which has been built and designed “smart” is what a smart home should be, not a home with an artificial intelligence which controls the appliances. A smart home is designed to adapt the circumstances to the consumers and allow the customers to apply their preferences in the house but since the automatic machinery can be easily installed in the system after the house has been built -which in fact is how most of the smart houses are being built today- a smart design which enables users to customize or adapt the house to their desires may change how smart houses are being perceived.

The main concern of this project was to enhance the characteristics of the machine for living to include a certain smartness quality, this in fact was reached by designing the ultimate customizable housing unit that is assembled on-site from prefabricated fragments that were built in factory controlled environment. A number of smart qualities were introduced in the research section of this book which were believed to be the answer to machine house’s shortcomings, now the question is if the result from the design can fulfill these qualities and project an enhanced version of the machine for living. Therefore The Smart Machine for Living will be tested in the same table to understand if it can be qualified as the enhanced version of the controversial machine for living concept.
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<th>Year</th>
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<th>Customizability (5x)</th>
<th>Cost effectiveness (4.5x)</th>
<th>Expandability (4x)</th>
<th>Stackable (3.5x)</th>
<th>Plugged-in effect (3x)</th>
<th>Quality of design (2.5x)</th>
<th>Demountability (2x)</th>
<th>Sustainability (1.5x)</th>
<th>Reusable (1x)</th>
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Research question

How is it possible to enhance the characteristics of the 1920’s “machine for living” concept to reach the ultimate mass produced housing principle aimed for a 2013 potentially high rise smart building?

The research question has been studied with two approaches in this book, the first approach was through research and the second approach was with design. The research section of this book has covered the generic smart qualities for the machine for living that could enhance the characteristics of the machine while the design section of the project tried to apply those qualities in a housing unit with prefab features.

The research unveiled the qualities which have been implemented in various other prefabricated projects but the solution to the main question was to combine all these qualities in a new system. As has been reviewed in the conclusions section all the smart qualities have been defined in the Smart machine for living therefore it could be assumed that the enhanced version of The Machine for Living should be introduced with these certain qualities. These qualities are the ones that if implemented the major failure factors from the main concept of the machine could be overlooked, hence demand a machine for living which will allow for a reversible architectural implementation. Reversible to the point that if the users were dissatisfied with their living machine they could disassemble their unit and re-assemble it based on their preferences unlike what happened to villas in Pessac village by Le Corbusier where people started manipulating their living environment but because of the limitations the manipulations where only limited to superficial modifications not fundamental modifications.

The main additional quality in the Smart Machine for Living is its customizability quality that allow for a complete house renovation without the conventional construction and demolition issues.

To answer the research question on the basis of “how a machine for living with all the combined qualities can be applied in a high-rise building”, the Smart machine for living has been design to be attached to a high-rise building while cantilevering from one side but the aluminum structure used in the units will comply with several other structural properties therefor these structures can simply be stacked over each other or be built on the ground over a foundation.

The Smart Machine for Living is the enhanced version of the almost incredible 1920’s Machine for Living by Le Corbusier.
Success or another failure?

If I am asked to answer this question, I believe it wasn’t a failure but the main aspect which could answer this question is whether or not the Smart Machine for Living could be built as a mass-customized product accessible to customers. This in fact corresponds to the final price of the end product or whether its customers will decide to actually take advantage of its competencies, and if it is indeed worth it to detach your apartment from the main structure for disassembly for a new interior organization. These questions will remain a mystery until maybe a day someone will either find this project alluring or someone will come up with the same idea and actually build it.
Questions (self-evaluation)

Have you stated the right amount of information needed for the thesis?
- I have stated all the materials relevant to the project.

Where do you think you can improve the thesis, in research part or the design part of the project?
- The research part I assume, and also if I could focus more on the aluminum unit instead of the high-rise the outcome of the project could be more sophisticated.

What would you change in the project if you were to work on the project again from the beginning?
- to be honest, Nothing, I adore the aluminum unit and the high-rise.

Are you satisfied with the result of the thesis? Design and research?
- Absolutely yes

If you had more time to finish the project in which part would you delve more?
- The construction method for unit’s interior partitions, and the participatory design section.

Have you found an answer to the research question?
- I believe yes.

Do you think your result and conclusion is sufficient enough for the thesis?
- To the extent that I have covered all my findings in the book and tried to explain them in the best possible way and show the results in the conclusion, yes.

Do you think you should have proposed a different research question instead of the one you proposed?
- Definitely no.

Have you achieved what you have planned for your thesis?
- In some sections I wish I had time to delve more into it, but for the rest I can report that I have done everything I planned to do in the beginning
References


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## Figures (References)


5. [http://xroads.virginia.edu/~ma01/lisle/30home/modern/lovell.html](http://xroads.virginia.edu/~ma01/lisle/30home/modern/lovell.html)


7. [http://designmuseum.org/design/r-buckminster-fuller](http://designmuseum.org/design/r-buckminster-fuller)


Appendix I (Participatory design questions)

1-Do you see yourself as a long term owner or there is a slight chance of moving out?

2-Do you see yourself in a house with a small balcony or in a house with an attached balcony to the outside?

3-Do you prefer to have a completely isolated master bed room or it doesn’t really make any difference for you?

4-Do you prefer to have a private garden in your household in a separate unit or you would want the garden to be part of your unit?

5-Would you like to have your household re-organized after a certain period of time? If yes please indicate after how many years.

6-Which type of housing do you prefer?
   - Studio
   - One bedroom apartment
   - Two bedroom apartment
   - Three bedroom apartment
   - A duplex two bedroom apartment
   - A duplex two bedroom apartment with an isolated master bedroom
   - A duplex three bedroom apartment
   - A duplex three bedroom apartment with an isolated master bedroom

   If your preference is not indicated above, please clarify your choice.

7- Do you see yourself in an apartment which is distributed in different levels or do you prefer a one level apartment, if your answer is yes please choose a type.

8- Do you or your spouse work at home? If yes do you need an isolated office with a separate exit?

9- Where do you want your house to be located in the building? (Height wise)

Each white rectangle represents a prospective housing unit.
Appendix II
results from target groups participating

Participant 1 (female architect)
28 years old

Answers:
1- long term
2- garden
3- not isolated
4- garden
5- yes
6- 3 bedroom duplex
7- first choice
8- yes
9- 1

Participant 2 (female architect)
28 years old

Answers:
1- 5 years
2- inside balcony
3- not isolated
4- garden
5- yes
6- 2 bedroom duplex
7- first choice
8- yes
9- 2
Participant 3 (female engineer)
28 years old

Answers:
1- long term 10 years
2- outside balcony
3- isolated
4- garden
5- yes
6- 3 bedroom duplex
7- first choice
8- yes
9- 1

Participant 2 (male engineer)
26 years old

Answers:
1- 6 years
2- outside balcony
3- isolated
4- none
5- maybe
6- 4 bedroom duplex
7- first choice
8- yes
9- 1 or 2
Participant 5 (male engineer)
28 years old

Answers:

1- Short term
2- outside balcony
3- isolated
4- garden
5- no
6- open bedroom separate on a different floor, 2 bedroom
7- first choice
8- yes
9- 1