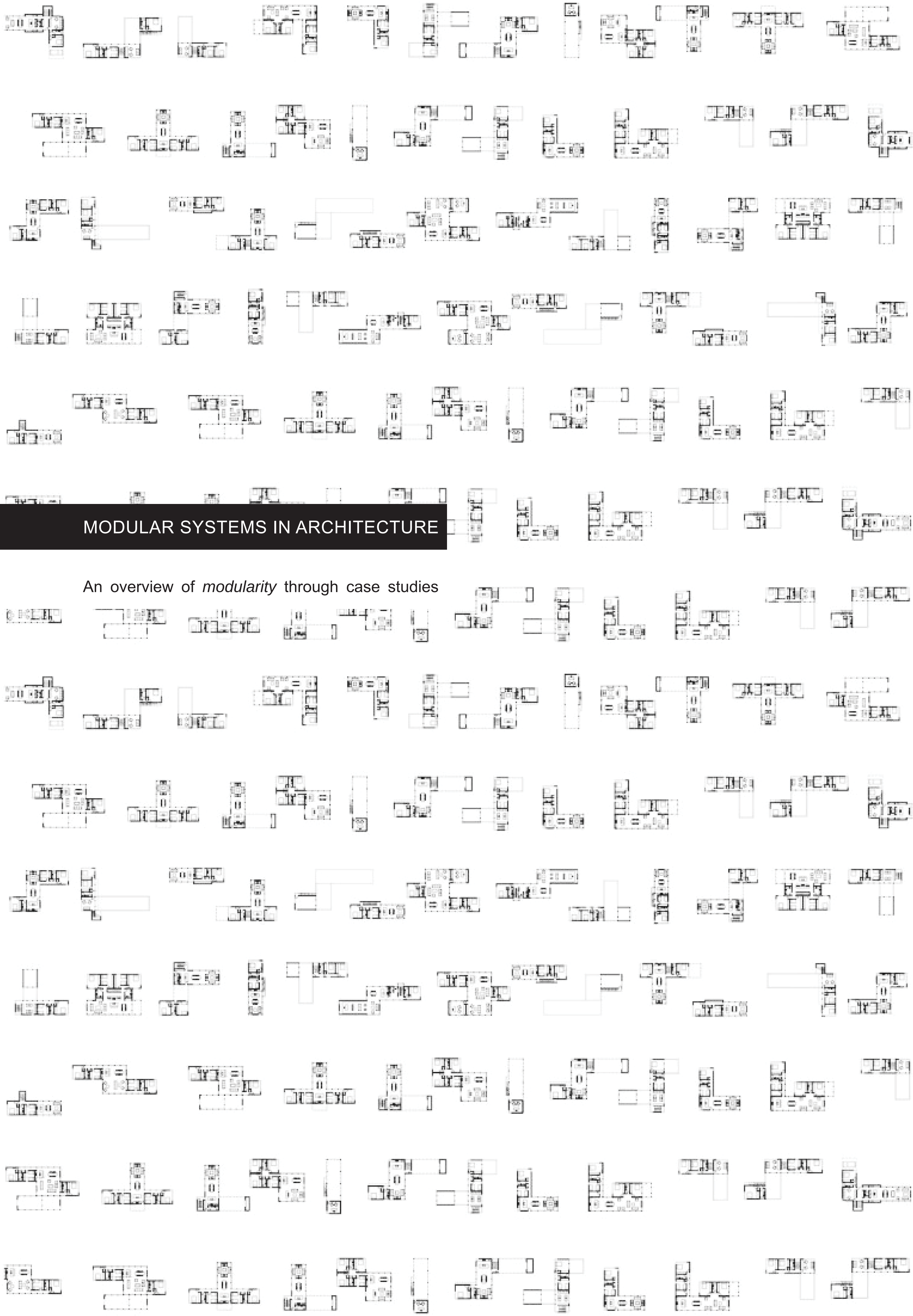

MODULAR SYSTEMS IN ARCHITECTURE

An overview of *modularity* through case studies

ESCUELA TÉCNICA SUPERIOR DE ARQUITECTURA
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An overview of *modularity* through case studies

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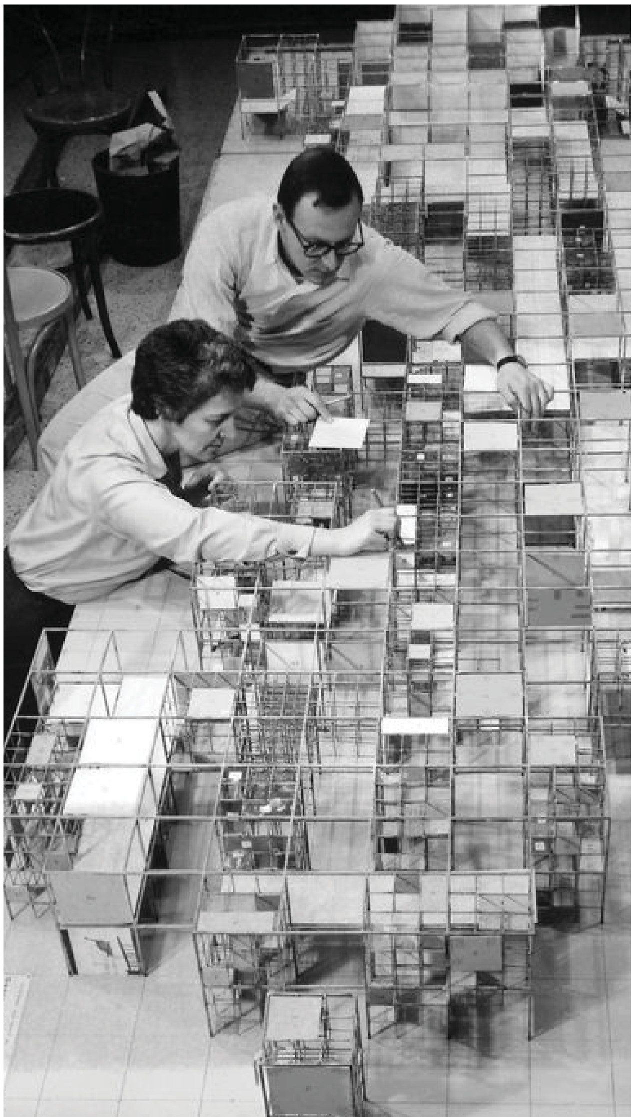


Figure 1.1 George Nelson. Experimental House - Vitra Design Museum. 1950

ABSTRACT. Inside the atmosphere of architectural design often appears a singular concept mainly surrounded by contradictions, vaguely defined and ambiguously applied. This term is used frequently to qualify not one but multiple conditions of an architectural object, causing major dissonances and becoming inevitably a question mark.

After having witnessed multiple approaches to the topic, it became clear that the same adjective was used to express different features of the objects in question. The overlap between the uses and meanings of the same term pointed out that there was a widespread and inaccurate usage of it: *modularity in architecture* is from now on the concept under study.

Commuting among multiple viewpoints inside the blurry atmosphere that involves the term, the investigation will focus specifically on clarifying the concept of *'modular systems in architecture'* and all the questions arising from it. More than venturing to redefine it, the research will be centered on revising the concepts and the theories attached, inquiring into its background, looking for review a group of cases to help decant the significance of this matter.

'Modular' –as an adjective- is a term that represents simultaneously a broad field of study as well as evokes a synthetic and very specific quality of the object, positioning it inside a unique category within the field of architecture.

It is actually possible to find multiple examples that commit with the concept at some point but the ambiguity that surrounds makes it not always be accurately employed. Generally, the term is applied to label multiple situations concerning, for example, spatial configurations, geometrical conceptions, materiality constitutions, construction techniques, even to utopic designs or prefabricated built examples.

The paradigm that supports this work is based on the conceptual approach of modular systems in architecture, primarily understood as those architectural designs that comply with the property of modularity in three major aspects simultaneously: modular space indeterminacy, prefabricated modular building system and modular growth and adaptability.

Synthetically, modular systems are identified with their search for undetermined spaces which dimensions and form are based on a strict modular design that subdivides the whole into equal parts. These systems require the minimum number of prefabricated building components, which in turn constitute an integral building solution. In addition, the adaptability to change, not only over time but also in uses and form, is to be contemplated in the overall design by given the capability to grow and the exchangeability of parts.

The dissertation will begin with a general introduction to the roots of the concept and the exploration of the related terminology, to position correctly the subject within its broad spectrum. It will gradually move to the review of specific examples, relevant for being exceptional architectural products, as well as their contributions made during its creative process. Finally, through a general overview, it aims to provide a wider understanding of the subject putting in relation all the concepts developed.

As well as clarifying the term, the work seeks to show that the genesis of these systems implies a complex thinking process that goes beyond the scope of the architectural design process. They have proved to bring significant progress in other related fields concerning the building industry and have approached the discipline to user preferences.

CONTENTS

1. INTRODUCTION

1.1 OBJECT. *Modular systems in architecture* represent just a small chapter within the vast conceptual universe that encompasses the entire discipline

Modularity as a quality, has been very loosely defined, slightly conceptualized and its definition is often contradictory depending both on the authorship and nature of the case under study. It's a subject widely complex and predisposed to ambiguity.

Significant contributions have been made under this label. Through describing, unveiling and exposing the subjects associated with this matter, the research will delve into a genuine approach of the concept and its both theoretical and tangible implications. Modular systems in architecture will be analyzed from the etymology of the terms to the complexity of the theories acquired through time.

Besides a general overview of the genetics of the modular systems, the cases under study will help greatly to highlight the main features. Three well-known examples -Moduli 225, The Packaged House and Espansiva-[1] will be under the lens to help reveal the nature of the concept, the implications of its design process and their contribution to the building technique development, moving towards framing the realm of application of the so-called *modular systems*.

The evolution of prefabricated systems and the industrial processes have proved to be a very complex scenario. Designers have been, for many decades, involved with the development of prefabricated solutions that hopefully result in effective responses to a concrete demand at a particular time. Most than a century of research and testing has passed and countless lessons have been learned.

In order to properly expose the cases under study, it's mandatory to evoke the great changes that architectural design and building processes have gone through the past century. This period represents the most revolutionary time span of all; industrialization introduced significant shifts and the world was conquered by technical progression. During this era, manufacturing, prefabrication and mass production achieved their highest steps into the evolution of the industrial processes. So did design.

Within the achievements made in architecture diverse examples can be found, some more revolutionary than others, the advances made in both theoretical and practical fields are extraordinary regardless the witnessed failures.

The introduction of technology encouraged significant developments as the novelty of new materials and the use of pioneer building techniques that unleashes the imagination of designers. Along history, prefabricated designs, some utopic and others feasible, have been proposed but its manufacturing haven't always been successful. The building industry has been always more resistant to evolve rapidly, but it is worth noting how these avant-garde designs have pushed the limits of the possibilities towards meeting users' demands.

Concepts as universality, neutrality, freedom, prefabrication, precision, effectiveness, adaptability, exchangeability and growth have been in the architectural agenda for decades, and history offers us examples that have successfully explored these issues. Those are generally known as 'modular systems' which constitute singular paths of profound research done in the fields of architectural design, industrialization processes, construction methods and mass customization.

1 Juhani Pallasmaa and Kristian Gullichsen, Moduli 225 System, Finland 1968
Konrad Wachsmann and Walter Gropius, The Packaged House System, U.S. 1941
Jorn Utzon, Espansiva System, Denmark 1969

Figure 1.2 Mid century experimental prefabricated house designs. 1940-1970

1.2 SCENARIO. Architectural design involves a complex process of multiple creative stages. An overview of these actions will set the scenario to host the next concepts that will be further developed. Architecture as an interactive and subjective discipline implicates a mix of ideals, actors and elements tightly related, contributing together to the configuration of architectural product.

Anne Beim exposes in her PhD. Thesis “Tectonic Visions in Architecture”[2], the idea that architecture has a close and bidirectional relation between three grand components: *envisioning, designing* and *building*.

When relating these concepts one first question arises: speaking of an architectural design mainly focused into aesthetics, Is it capable to determine a building construction system considering the techniques and technologies involved, or is it backwards? From our position, systematic and abstract design regarding modular systems nourishes from the knowledge achieved through advances made in technology, which are only possible since design pushes the limits of the industry to new and better technical solutions.

What comes first? At least it’s possible to recognize that the theoretical and practical components which define the discipline continuously relates back and forth. The constant feedback between both fields promote the emergence of new vanguards filled with utopic ideas and with them, there comes the improvements of the building techniques and manufacturing processes that make them feasible. The design process involves paying extreme attention to each of the parties equally.

When speaking of design processes, this first imprecise idea rambles around our heads it’s known as *envision*. In architecture, it represents the first intangible lines of a project and reflects the desire of rethinking the present conditions. It is a start point that encourages new approaches of a prevailing state of art.

The attempt of materializing what were mere intentions would be the so-called *design.* It is defined as the manifestation of the ability to imagine space, perceive its function and assign a formal expression. The designing process isn’t lineal, much less simple. It is to be shaped by other external circumstances as to say, the extended range of existing materials and current technologies. On the other hand, design forces might stimulate innovations on the fields involved that were not yet fully explored.

Putting envisions and design into practice it’s what *building* is about. It will represent the step where reason and building processes relates in their greatest level of understanding: *tectonics* as the poetics of making, *technique* as the method of making and *technology* as the knowledge of making.

All these concepts, are absolutely and unfailingly related to the process involved with the development of a modular systems and none of them can be left out. Modularity implies envisioning the game board, designing the set of rules that will master the creative process and choosing the appropriate technology for developing the building system. The conception of modular systems should contemplate very carefully each scenario in order to acquire the specific attributes concerning space, physiognomy and flexibility they require.

2 BEIM, Anne, Tectonic Visions in Architecture, Arkitektens Forlag, DK, 2004

"Architecture wrote the history of the epochs and gave them their names. Architecture depends on its time. It is the crystallization of its inner structure, the slow unfolding of its form".

MIES VAN DER ROHE, Ludwig, Architecture and Technology, Architectural Review vol.67, no.10, 1950,

1.3 SCRIPT. The work is divided into three main chapters which discusses different issues concerning the modular systems from multiple perspectives. The purpose is to reveal the conceptual depth associated to the term layer by layer, getting finally to a complete definition and understanding of its major implications.

The first chapter intends to position the term and its variants through an etymological perspective, delving slowly in its meaning and background. Since the use of the module dates from ancient times, it's essential to go backwards to fully read the complexity that surrounds the notion of modular systems. The function of the module as a reference unit of measurement positions it as a fundamental tool for achieving a bounded and hierarchical design. Its development and evolution is directly associated with the social and historical context in which it is conceived. A quick review throughout history, focusing on the evolution of design and construction industry, will expose the natural associations of concepts that have added complexity to the term.

Once the term is framed and its main features are revised, the following chapter will focus on the overview of few selected key cases, which are decisive to mature the vision of the topic and will help greatly to clarify the conceptual universe where modular systems perform.

Three exceptional cases are being exposed to explain the major subjects that define modular systems: the pursuit of a design that leads to an absolute architecture where *universality* is achieved in every aspect, the *systematization* of the building components and assembly processes to gain effectiveness and reduce costs and finally, the search for adaptability through time explained by the *additive principle* that proposes an organic approach to the evolution of buildings. The work revises the historical and technical aspects involved in each case.

The Moduli 225 system, by the hand of J. Pallasmaa and K. Gullichsen represents faithfully the exploration and the achievement of the highest degree of abstraction in design and indeterminacy of the spatial conception, showing a search for absolute aesthetics and the refinement of the building components.

W. Gropius and K. Wachsmann, made relevant contributions to the notion of building systems in architecture, having achieved its finest example with the design of The Packaged House, a prefabricated construction system of great simplicity and maximum opening accomplished by the modularity of the pieces, the high complexity of the joints and the and comprehensive planning of the prefabrication process.

The Espansiva system is both a faithful representation of the additive theories developed by Jorn Utzon and an exquisite solution for the demands of adaptability through time, program and user's will of customization acclaimed by contemporary architecture.

Each of them also complies in their own way with the concepts developed for the others, but the study will just emphasize the greatest virtues of each one: the spatial configuration, the building processes and the adaptability through time and uses. Having the concept of modularity being molded, a following comparison chart will put the cases into relation to decant their strengths and weaknesses, so the idea of *'modular systems in architecture'* may finally be solidify.

2. TERM

2.1 ETYMOLOGY. In order to describe a particular quality of an architectural object, adjectives are free for general use. '*Modular'* -applied to systems- is precisely the term under study which will be, from now on, the center of the discussion.

Back to the roots of the meaning, the most elementary definition involves the concept of *'module',* understood as the very basis of design processes and building techniques. According to Oxford Dictionary, 'module' is as a term used to express an absolute value, a constant factor or ratio.

It's origins dates from mid 16th century when it was first used to denote an architectural unit of length ('modulus'). It comes from Latin, which literally means 'small measure'.

As moving towards multiple idiomatic variations, an even more complex term pops up: *´modularity´*. This noun expresses the degree into which system's components are separated and recombined.

However, the meaning of the word can vary depending on the context. Modularity expresses a feature of an object and it happens to have numerous valid applications depending on the field of study and the period in which the concept was placed in service. For example, the term is most commonly used to describe the implementation of a standard fixed unit of measurement (module) that concludes in a proportional architectural design (modular design). Modularity, is also commonly applied attached to the theory of building systems, concerning the exploration into spatial grids (modular space) and prefabrication of parts (modular building systems).

A more contemporary approach within the field of building construction, it is used to refer to the technique of putting together industrial standardized elements to form a larger unit (modular prefabricated units).

It's usual to run repeatedly into other words used to refer somehow to the same concept, that aren't precisely synonyms but are used sometimes as substitutes. These terms manage to express some big feature of the object under study and are shown often as complements that help greatly build the concept of 'modular'. The words are: *linked, segmental, sectional, flexible, integrated, prefabricated.* By digging into these concepts, some clues about the nature of the real notion of modularity came up.

The nature which involves the term *linking* highlights the act of connecting parts. On the contrary, *segmenting* is about splitting something into small units*. Flexible* is related to being adaptable and refers to the possibility of embracing change. *Integrate* is about bringing together, combining, incorporating into a whole. It can also be found that modular is inaccurately substituted with the concept of *prefabrication*, which is actually about 'manufacturing something in standardized sections ready for quick assembly'. Every concept is unfailingly related, describes a singular feature of it but still shows just a small portion of the universe that involves 'modularity'. They manage, all together, to represent the first approach to the term under consideration.

Having framed the atmosphere of the term, a more accurate definition of it is still missing. 'Modular systems in architecture' represents a singular result of a combination of a wide range of concepts, in order to constitute a very complex, universal and almost utopian way of conceiving architectural design.

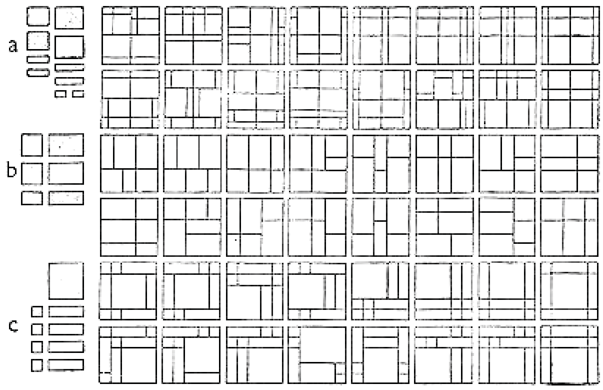


Figure 2.1 Le Corbusier´s The Modulor. A harmonious measure to the human scale universally applicable to architecture and mechanics. Faber and Faber. London. 1954

2.2 BACKGROUND. Modularity in architecture is usually related with a particular design method which masters the geometry, determines the rhythm and propose an equal subdivision of the space. Simultaneously, modularity concerns technical aspects linked to the genetics of the building systems as the manufacture of elements, the assembly methods and industrialization processes.

Since Ancient Greece the term was historically linked to the use of standardized measurement units, which regulated the general dimensions, the building proportions and the overall design of the components. At that point, one single element strictly geometrically defined acted as a module, being subordinated to a set of rules that managed the whole building process. Being defined the method of arrangement, this basic unitary element, used repeatedly, created a construction system based on standardized pieces.

The use of standardized construction elements as a systematization of construction processes has been among us since the very beginning. The same manufacturing patterns concerning the building process can be identified until nowadays although the industry has suffered great changes over time; the use of reigning measurement unit systems, construction by addition of prefabricated elements, systematization of building processes, among others, still follow recognizable patterns.

Romans played a main role in developing and spreading the knowledge about systematized construction processes by employing precut stone elements under strict design regulations well-known as classical orders. The T*en Books of Architecture* by Vitruvius defined the instructions for modular building systems made of stone based on proportions criteria.

Japanese tradition played a key role in the evolution of modular design. They managed to preserve a basic dimensional order that subordinates the whole design, the production of prefabricated building elements and the systematized assembly techniques. The *shaku* determined the modular layout for the room dimensions and relationship of elements. Prefabricated modular panels were used to fill the distance between columns.

The Japanese house is an early example of a basic modular arrangement and of standardization and unitization in timber construction.[3] It's not surprising that Japanese traditional architecture is still glorified as one of the most humanized of all. It is traditionally based in the dimensions of the tatami mats (0.91 x 1.82 m) –type of flooring used in sleeping rooms-, in which the living spaces are defined as multiples of the minor unit. It is remarkable how many great advances in the standardization of construction elements are nowadays based on highly refined levels of craftsmanship and functional details coming from this antique knowledge.

It's also important to highlight that many significant studies have been done along history in order to find a harmonious and anthropometric system of measurement. *Leonardo Da Vinci's Vituvian Man, Leon Battista Alberti's De Re Aedificatoria, Le Corbusier's Modulor* represent key studies devoted to improve the general aesthetics -speaking about rhythms, scale and proportions- and function, all based on the golden number.

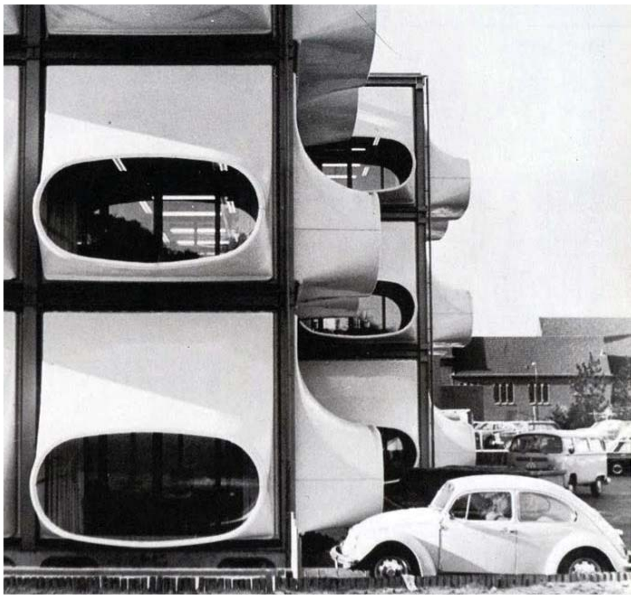
Modular design in architecture has been sometimes tightly linked to a pure geometrical and spatial approach of the master design and more recently to the building industry as a mean for optimizing the procedures and improve results.[4]

3 DETAIL Components and Systems: Modular Construction, Design Structure New Technologies, Birkhaüser, Munich, 2008.
4 KNAACK, CHUNG KLATTE, HASSELBACH, Prefabricated Systems: Principles of construction, Birkhauser, Berlin, 2012.

“You cannot imagine what it meant to me to come suddenly face to face with these (Japanese) houses, with a culture still alive, which in the past had already found the answer to many of our modern requirements of simplicity, of outdoor-indoor relations, of modular coordination, and at the same time, variety of expression, resulting in a common form language uniting all individual efforts.”

Walter Gropius. Architecture in Japan. 1955

Figure 2.2 Tatami mats flooring and sliding rice panels divisions used in traditional Japanese homes since the Nara Period (794-1185)



2.3 Laurens Bisscheroux. Bureaux AZM, Netherlands. 1972

2.3 PROGRESS. Multiple unrelated fields of study have developed their own concept of modularity. Historically, the term has been applied in a great variety of forms. The idea of 'module' as a unit of measurement is the most basic approach of the term possible. However, it has changed greatly geographically and through history. Traditionally, design and construction has been ruled by the ideals of harmony, hierarchy and proportions prevailing at that time. Astronomical, cosmic, aesthetically, humanistic and constructive alibis have been chosen to define superior order that masters the discipline. Over time, the concept has evolved together with design theories and advances concerning tectonics. The ideal of modularity became more complex but its basic nature remains.

Modularity crosses over multiple disciplines and certainly over multiple scales of the design process; from the definition of single building components to the whole building systems, from the conception of minimum living cells to the arrangements of complex flexible habitats. Modularity, as a feature of an architectural design, brings with it the power of openness, freedom of indeterminacy and precision of their assembly system.

It is worth remembering that great advances on the subject were achieved in the past century -postwar period- when housing and materials were scarce and architects had the opportunity to develop many light-construction systems, or even dream about new ways of living. Since then, still lingers the notion of modular architecture being a result of utopic ideals of the early 1960s in which temporary, mobile and experimental ways of living were proposed and new materials and cutting edge techniques of construction were developed.[5] Nowadays, very distant from that time, the term is commonly employed for describe standard prefabricated off-site assembled units, an indoor building method that proved to reduce project duration increasing quality and control techniques. These references are not only used slightly inaccurate but also reduces the scope of a concept that is broader and has deeper meanings laden.

The focus of this work is put on highlighting the main features associated to modular system design and review the advantages of this complex design process. To achieve this goal, is necessary to make a quick overview of the great advances made in history, deeply analyze some outstanding cases and expose the many attributes of the concept.

As an introduction to the realm of modularity, the extract shown below expresses through a very basic example, the possibilities and consequences of designing and building on the basis of a module –unit of measurement-:

"In residential design, the minor workable module seems to be the 16" weave, which corresponds to the Cubit – or its half 8", which is the Hand Span. No wonder that we should use as the unit for man´s shell the dimension of his working unit: the force-arm or cubit. It explains the fantastic success of the most popular masonry unit of today: the cement block, which has for dimensions 8x8x16": 10 blocks make 6'-8" a perfect height for a door, 4 blocks reach the window sill, one block Is the height of a step, 2 reach a seat, 3 make a table"[6].

What stands out from this is the idea that the establishment of a basic unit makes the whole design process go straight forward to a result where every decision made is related with the previous and the following determination. Modular design follows the same pattern.

5 SMITH, Ryan E., Prefab Architecture: A Guide to Modular Design and Construction, John Wiley & Sons, US, 2010, Ch.6.3 Modules
6 GRILLO, Paul Jacques, Form, Function & Design, Dover Publications, US, 1975. Pg 153

In media, the network is composed by self-sufficient parts, or modules. In the study of networks, modularity is used as a unit of measurement of the quality of a division into groups or communities. Modularity is considered one of the 3 most important features in the ecology supporting resilience. The mind is supposed to be composed of independent, closed, domain-specific processing modules. Industrial design is based on the modularity of an engineering technique where larger systems are built by combination of smaller subsystems. In manufacturing refers to the use of exchangeable parts in the fabrication of an object. Software design uses the term to define the logical partitioning that allows complex software to be manageable.

Definition of Modularity. Source: Wikipedia

ANCIENT EGYPT
KEOPS. Proportions defined by the golden ratio, associated to astronomical and cosmic matters
Cubit=523mm

ANCIENT GREECE AND ROME
VITRUVIUS. Number worship and geometrical relations and proportions found in Temple's physiognomy
Classical Orders

FAR EAST
Traditional construction governed by measurement units and systems
CHINA. *Toukou*, variable length but proportional within the building
INDIA. *Prajapathya*=1.25m
JAPAN. Tatami mat 1x2 proportions. *Ken*=1.818m.

RENAISSANCE
VITRUVIO, PALLADIO, LEONARDO DA VINCI.
Human body studies to relate proportions
Golden Ratio Φ=1.618

INDUSTRIAL REVOLUTION
PAXTON. First modular industrialized steel construction based on a modular grid.
Measurement basic unit: 8ft

MODERN MOVEMENT
LE CORBUSIER. *Modulor* links the golden ratio, the metric and imperial systems in relation with the human body dimensions
Measurement basic unit: 2.26m

POSTWAR
NEUFERT define the German basic unit=1.25m
WACHSMANN uses in the Packaged House the module=1.016m

Figure 2.4 (Left) Buckminster Fuller. Dymaxion Deployment Units in North Africa. 1944
Figure 2.5 (Right) American Lustron Homes. Post-war experiments in prefab housing made of steel and coated with porcelain enamel, manufactured like cars and transported by trucks. 1948

INDUSTRIALIZATION. The evolution of humanity and resulting technical advances, encouraged the development of new building solutions. By the end of the XIX century, the industrialization era came up with innovative housing systems. By that time, large amounts of processed timber was available so more simple and cheap construction methods where developed. One outstanding example was the well-known '*Balloon Frame'* system that consist of wooden construction elements with a standard spacing between studs that were directly related to the tree trunk dimensions.

Military expansion helped greatly to the development of the building industry and it wasn't only to meet the need of accommodation and storage facilities. Steel, aeronautical and mechanical industries were growing intensively and the achievements concerning building techniques and emerging new materials, where feasible to be transferred from one industry to another. The abundance of steel at the beginning of the industrial revolution, introduced new possibilities for building.

One major reference of that era was the *Cristal Palace*, designed by Joseph Paxton for the World Exhibition of 1851 in London. The frame based building was conceived by the connection of a short number of standardized units, based on the principles of modular arrangements. The basic module was defined by the maximum size of the glass pane that could be mass-produced at that time.

Although great advances were made in this era, modular design was conceived only based on a measurement unit module that masters the pace of the main structure. The production of standardized elements was the first attempt to systematize the building industry and provide the first clues for further developments.

RATIONALIZATION. The rationalization of the architectural design came hand in hand with the changes in the building industry. New quality standards were established and new manufacturing techniques were applied.

Industrialized machines, cars, ships were inspiration for new architectural forms, thinking and production. The 19th century working class demanded rapid solutions for their housing needs, and better quality standards could only be achieved using industrial techniques. The *standardization* of the components became decisive for progress of architectural design

First World War left leading countries with a severe shortage of building materials and many inactive industries that took on the role of developing new housing systems. In the 1920s, architects research was focused on timber and steel construction systems. During those years mainly in the United States, a significant collection of '*construction kits*' as do-it-yourself catalog homes where offered in the singular housing market -Sears, Aladdin, Lustron-.

There was also a willingness to explore new paths on the development of transportable prefabricated houses and Richard Buckminster Fuller was one of the driving forces. His first 'living machine', the *Dymaxion House* was developed in 1927, created with lightweight materials (steel and aluminum) to create maximum of space with a minimum area.

Panelized systems were intensively developed in the 1940s and Konrad Wachsmann in collaboration with Walter Gropius created the *Packaged House System*, a grid-based modular timber system where constructive elements were simply connected by hooks, created with the aim of being the most complete prefabricated system possible.


THE LUSTRON HOME

Figur 2.6 Pierre Koening. Case Study House #22 construction phase. Los Angeles, USA. 1960

STANDARDIZATION. Second World War upcoming years along with its economic and social lifestyle changes, widely favored the demand of singular housing.

John Entenza's "Case Study House Program" launched in 1945, together with his eight commissioned architects (Charles and Ray Eames, Eero Saarinen, Richard Neutra, Rafael Soriano, among others), was intensely focused on producing industrially prefabricated prototypical houses with a great amount of effort put into architectural design. Case Study No 8, designed and build by the Eames by 1949, using mostly industrial products sold by catalogue, came to embody the model of modern living and architectural design of the post-war years.

The peculiar 1960s were the cradle for the driving and visionary Metabolist movement lead by K. Kitutake and K. Kurokawa, together with other Japanese architects. Their work on capsule agglomerations inserted into a primary load-bearing structure set the bases for designing as from modular volumetric units. Moshe Safdie's Habitat 67 and Richard Dietrich's The Metastadt were others modular design attempts to offer new housing and urban solutions.

The great demand of dwellings and the associated pressure to build the fastest and cheapest as possible encouraged the long awaited systematization of the building industry. Industrial prefabrication and standardization of the processes were supposed to respond quicker to the present needs and the rush had its implications on the general appearance of the building; constructive elements were serially produced, floor plans and facades came to be as modularized as possible, as well as the building form was extremely simplified.

SYSTEMATIZATION. A greater degree of openness was claimed for the housing design developments. None of them gave complete solutions to the individual requirements of the users, being resistant to later alterations. Residents called for more flexible dwelling concepts and building systems.

These worries gave birth to a whole new concept: *open systems* embraced the ideal of providing rules, not materiality or aesthetic guidance, by which many subsystems produced by different manufacturers could be combined to create new building systems. Elements should be compatible in order to be melded into one organism, completely coordinated and absolutely replaceable.

Not only openness in technical aspects was tried out by that time, but also the flexibility of the building to be adaptable for different uses. Some examples explored the ideals of being simple empty frameworks that were supposed to be completed according to the user´s specific needs.

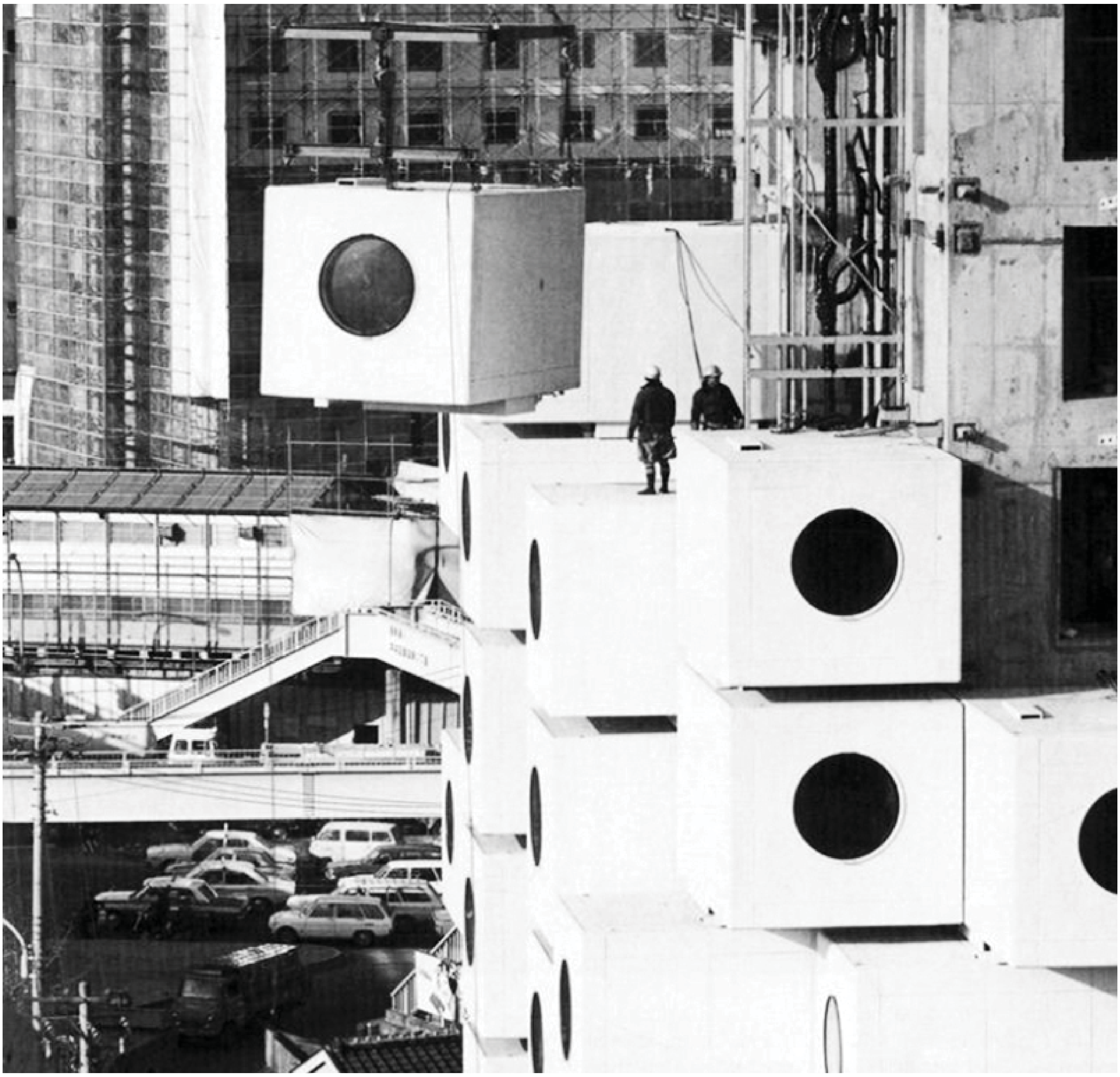
Utzon's inspiration on CSH movement and traditional Japanese dwelling design was reflected in his *"Additive Architecture"* manifesto (1970). Within the system, main former elements were individual room types that allowed to be freely combined and create large structure that acts as a living organism in constant change.

The 70s were about contradictory research lines that went from development of building systems of housing focused on finding rules for putting together and highly coordinated construction elements already existing in the market, and on the contrary, for a profound criticism of the post-war urban development era. Technological progress reached its own limits and a crescent environmental consciousness reduced greatly the euphoria for technology.

Ernest May claimed "the mechanization of the housing industry in particular should be encouraged. The goal must remain the factory produced dwelling –including internal fittings- that can be delivered as a complete product and assembled in a few days."

Ernerst May. Guidelines for Rationalization of Housing Construction for the Minimum Existence

Figure 2.7 Kisho Kurokawa. Nakagin Tower, Tokyo, Japan. 1972



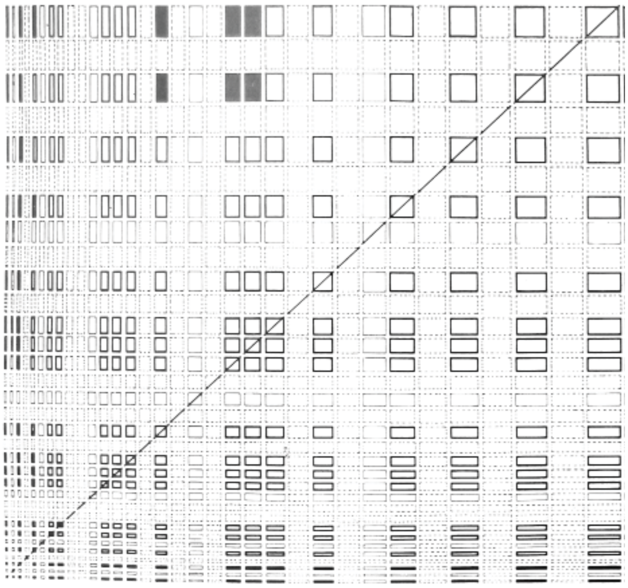


Figure 2.8 BRS. Building Research Station Module Chart. UK Standard opening sizes study for mass production and building industry development. 1960

2.4 DESIGN PROCESS. Modular design isn't only about establishing a unit of measurement which better meets the needs and define the overall scale of the project involved. In its most complex conception, modularity in architectural design is about setting a *system of rules* that relate simultaneously –under strict guidelines-, measurement units, proportions, rhythm, inner space dimension, physiognomy of the construction elements, joints design, assembly methods among others. The coordination of all these variables is one of the greatest difficulties that faces modular design.

From the point of view of the design process, the establishment of modular *coordination* might be seen as a restriction of freedom of the composition, meanwhile it opens a whole new dimension of options and compositional variations. On the other hand, modularity translated into the inner space will provide restrictive subdivisions but offer flexible distribution of the living spaces.

Within modular design, it's truly a requirement to reach high levels of refinement in the design stage. Coordination is necessary towards achieving the essential affinity between the theoretical geometrical design, the fabrication and building processes.

Modular coordination, in this case, is a key component which link two worlds that are not always properly harmonized. The additive nature of the construction process makes it imperative to have a regulation system in order to proceed correctly during manufacture and more even during the assembly process. Modular coordination leads to a simplification of the fabrication process, promotes the interchangeability of the parts and provides efficiency to the construction process.

Architectural design isn't an exclusive product of a set of rules that leads to an already known final result. When venturing in these systematic design processes, numerous variables have to be managed, linked and combined. In addition, time and place conditionals deserve the same consideration as the technical background and formal intentions.

Design based on the principle of modularity tend to be singular, based on processes by other systematic through a strict methodology, which constitute a work of art by its own.

The intrinsic qualities of the process of modular design tends to achieve the highest grade possible of universality regarding its form, function and aesthetics, a condition that worth to be highlighted and reviewed along with the resultant final product. Neutral spaces, simple aesthetics, exchangeable building elements, easy assembly procedures, volume growing and constrains possibilities, among others are some features given by modular design process.

It is noticeable that the rules applied to the creative process somehow limit the final appearance of the object which is being conceived. They sort of establish a simplified and repetitive pattern, define a limited number of compositive elements also conditioned by the current technical achievements and determine a limited catalog of materiality which also directly depends on the industry current developments.

However, these processes naturally open the doors to a whole universe of formal and conceptual possibilities. Once the main elements are defined and many combinations are proved to be possible, the spectrum of future imaginable arrangements significantly enlarges.

(About Japanese houses) The floor plans are admittedly open, but the individual rooms are clearly marked one by one in the sizes determined by the fixed size of a mat... The rooms can either be divided from each other or united with each other or with the garden to enable an interacting milieu. In this way the plan is flexible, a feature it shares with modern buildings constructed of load bearing frames. But this flexibility does not at all mean the dissolution of spatiality. Each room retains its autonomy and its clear delimitations, even though its walls are made of paper.

AHRBOM, Nils, Spatial Design: Philosophy or Architecture?
Excerpt from ASGAARD Andersen, Michael, Nordic Architects Write.
A documentary Antology

GRID. One of the most characteristic features of modular design is its subordination to a superior order governing each of the stages and components. It's imperative that a higher hierarchical system is established so the design is determined by the effectiveness and clarity of the rules imposed.

Not only the imposition of a basic measurement module is needed -a module that will be multiplied and grow more complex to determine the final draft- but it will also be required a very precise coordination of the parts themselves and the parts to the whole.

How modular coordination is achieved depends of the use of the *grid* as a basic design tool. Once the module is defined and the general scale is set, its mandatory to review the definition of the design grid that would condition the project.

The grid is a geometrical system that determines the position and dimensions of modular building elements. The basis is provided by a spatial network of dimensional lines generally based on a square or rectangular system. Planes, lines and points of reference, whose distance apart is based on the primary module or multiples thereof, are required to define the relationship of the individual building elements to each other. From these coordinated system, based on two-dimensional, planar grids or three-dimensional spatial grids can then be developed. The planning, manufacture and assembly of the building elements are based on this system.[7]

Modular coordination had become an ambitious matter on which designers have to take an active role to make the most of it. As seen before, there exist common design and constructive issues that require focusing on the coordination of the parts and the whole. This also provides not only order but also conceptual and functional richness, favoring the possibility of adaptation to the surrounding environment and promoting transformation to comply with the required uses and the many possible costumer's will.

Many considerations have to be taken into account in order to make modular design architecture feasible and functional. Measurement systems, margins of error and tolerances have to be granted in the full process and effectively agreed between all parties. The more energy is put in the development of a strict modulated design, the more feasible will be the coordination of elements.

The most extreme idea about this matter states that the grid's main objective is to assist the designing of the perfectly-coordinated building into which standard building components could fit without any major obstacles and be exchanged or replaced freely. And this hypothetical synchronization of the whole design may also favor the replacement of bigger spatial units or even allow the mutations in functional arrangements and provide variety of uses.

To make modular designs tangible building systems, the implementation of design tools that help gain precision are the key element that favor the transition and lead to perfection.

Design tools might be considered at first glance, as supporting elements to help develop the initial idea, but they also serve to launch complex design processes. Modular design coordination was widely rehearsed and developed to a high degree of refinement through last century, despite of the unsophisticated building technologies available at that time. Great architectural examples were conceived under these guidelines and many design theories were released together with outstanding building systems.

7 DETAIL Components and Systems: Modular Construction, Design Structure New Technologies, Birkhaüser, Munich, May 2008. Pg 44-45

Figure 2.9
A. Standard Grid. Structural equal subdivisions
B. Classical Grid. Symmetric irregular subdivisions
C. Miesian Grid. Facade independent from structural regular subdivisions
D. Exterior grid. Modular Facade
E. Interior grid. Modular inner space

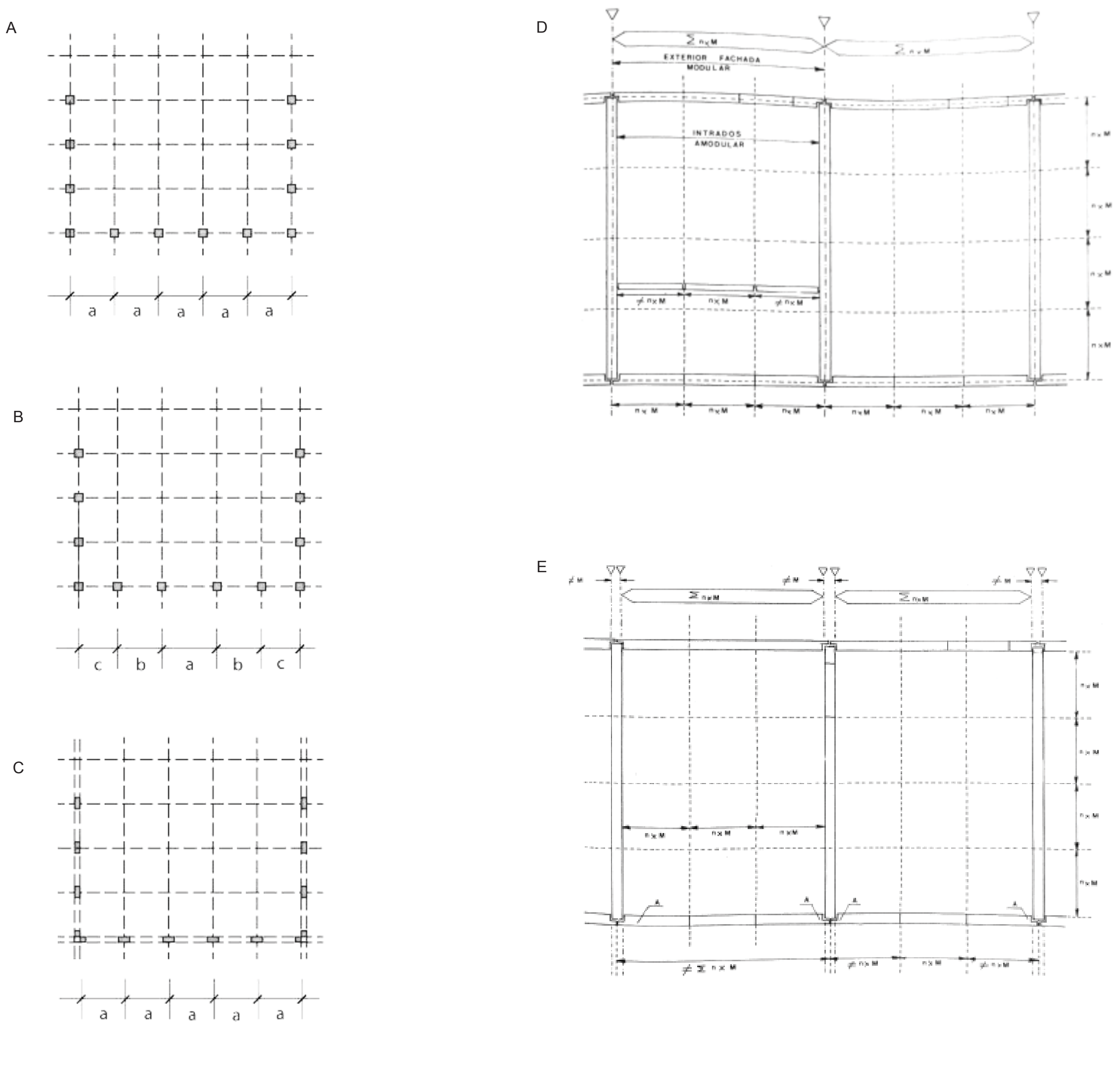


Figure 2.10 Richard Dietrich. Metastadt-Bausystem. 1972

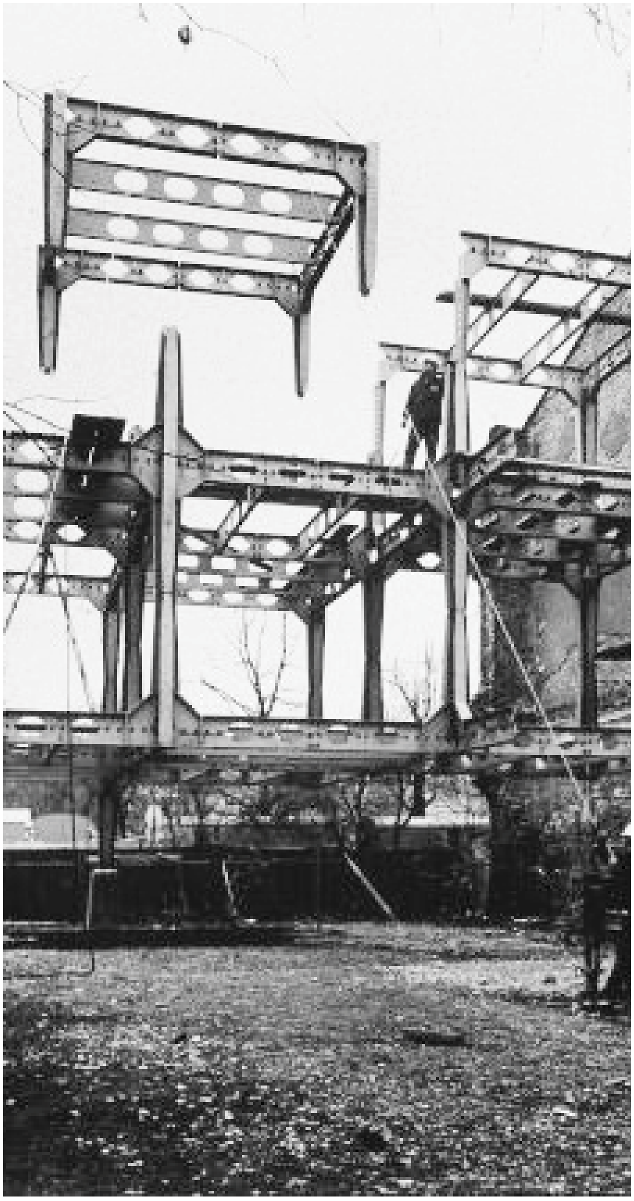
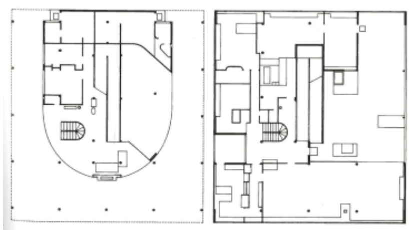


Figure 2.11
A.Le Corbusier. Ville Savoye
B.Paul Rudolph. Guest House
C.Mies Van der Rohe. Lake Shore Drive
D.Sou Fujimoto. Wood House
E.Arne Jacobsen. Kubeflex
F.SANAA. Zollverein Center

A



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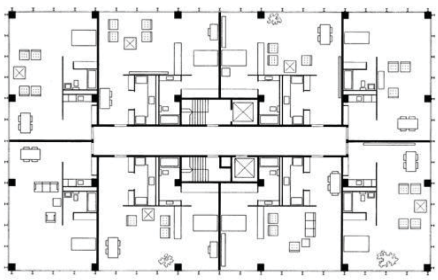

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Figure 2.12 Kisho Kurokawa. Agricultural City model. Aichi, Japan. 1961

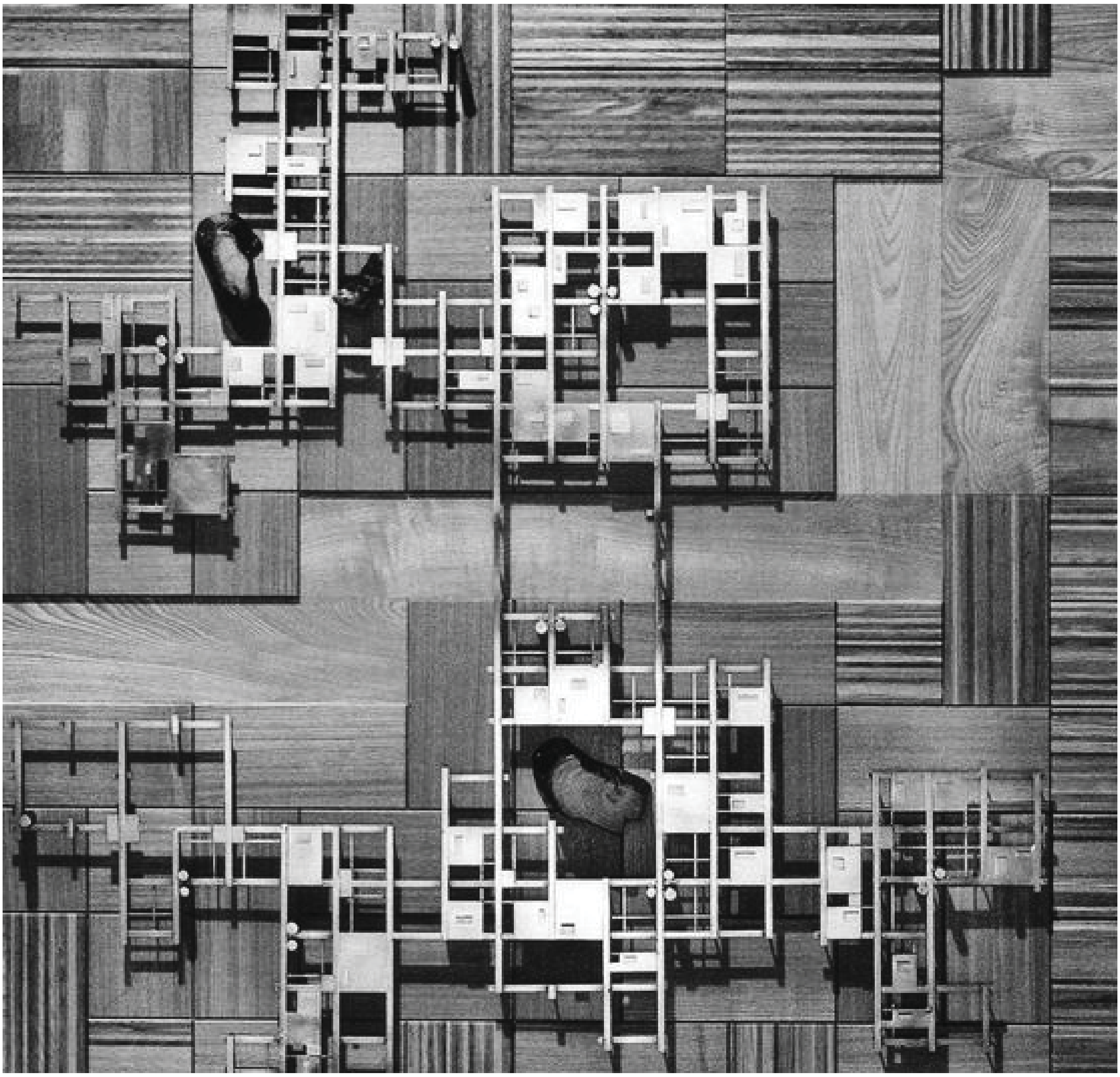


Figure 2.13 Sears, Roebuck & Co. Sears Catalogue Homes. 1908-1940

2.5 COMPONENTS. As seen before, the design of modular systems implies following certain strict determinations and using some specific tools in order to set out the bases for the whole process. It involves in first place the definition of the general proportions which is naturally followed by the determination of a spatial coordination system that leads to the systematization of the entire design.

As we move into further appreciations, the term naturally morphs into more complex shapes. So until this point, modularity was described as the sum of the coordination of the general design and the precise definition of the building components with its corresponding assembly procedures. In brief, modularity involves every aspect of the process of design and every detail has to be considered, coordinated and taken into the genesis of the development of a building system.

As part of a building physiognomy, the design of each element is decisive for defining the nature of a building system. Components are a combination of elements to be employed in a building construction in order to accomplish the functions and aesthetics goals of the project.[8] Shaped as simple or composed, these constitutive elements have their own features, logics and limitations that are translated directly into the design process, the construction method and the resulting building composition.

In terms of components, modularity can be defined from the physiognomy of each individual element as they stand as *linear, planar* or *three-dimensional* which its arrangements to form complex elements, in order to build major configurations.

The elements themselves determine the spatial composition of the whole and its geometrical nature will be essential to define the sort of proposed modular system.

Modules can be either way individual element. As is cited in the text, *Prefabricated Systems. Principles of construction*, "modules consist of individual elements. The result is a complex construction system from which a well-systematized and prefabricated structure can be created because it is based in complete modules or subsystems".[9]

From this point of view, the concept of module is associated to standardized and interchangeable parts of a construction system that has been designed for easily assembling to be part of a whole. Elements can be considered as modules themselves buy there will always be a major spatial modularity that set the base for the components design.

Going further still, the interrelation of individual elements that creates a major and more complex composition constitutes what is known as a system. In the field of building construction, these concepts refers specifically to the way how smaller and singular components are put together to create a whole based on hierarchical relations ruled by assembly techniques.

The definition of a protocol of design and construction material catalog from which the system will be developed, will determine the final set of compositive elements. The morphology, its size, its function within the system, the manufacturing process, the type of assembly with the other components and the mounting process are preceded by a conscious design of each element that constitute the building system.

8 SMITH, Ryan E., Prefab Architecture: A Guide to Modular Design and Construction, John Wiley & Sons, US, 2011 Chapter 6: Elements
9 KNAACK, CHUNG KLATTE, HASSELBACH, Prefabricated Systems: Principles of construction, Birkhauser, Berlin, 2012.

Le Corbusier claimed that "re-evaluation of existing values is the re-evaluation of the essential elements of the house. Serial construction relies on analysis and experimental research. Large industry must address building and produce individual building elements in series. The intellectual requisites for serial production must be created."

Le Corbusier. Towards an Architecture, 1923, Ch. Houses Produced in Series

PHYSIOGNOMY. The physiognomy of the primary components is a deciding factor for defining the classification chart of a modular building system. *Linear, planar* or *spatial* elements determine the nature of the system.

When is comes to label these systems, much of the literature agree on a possible rating system. As an example, *Edition DETAIL Components and Systems* describe a component-subordination classification system respectively: *frame, panel* and *room unit* modular systems.[10]

Prefabrication may be also classified by the extent to which elements are completed prior to assembly on site. Assembly methods that define prefabricated building systems are directly related to the morphology of the main construction elements and the possibility that they provide of being assembled off site, depends directly on its geometry, materiality, scale and complexity.

As it was mentioned before, most building systems that are available on the market today are classified within three main categories being described below.

Some systems appear to be more flexible than others depending on the capability of these elements to be manipulated, transported and assembled. The most complex the constitutive elements are, the highest amount of off-site work is needed but quality control is won. The simplest they are, more in site work for assembly is required and higher amount of time consumed.

The next step will be the review of the main features of three systems categories in order to properly position the selection of cases under study.

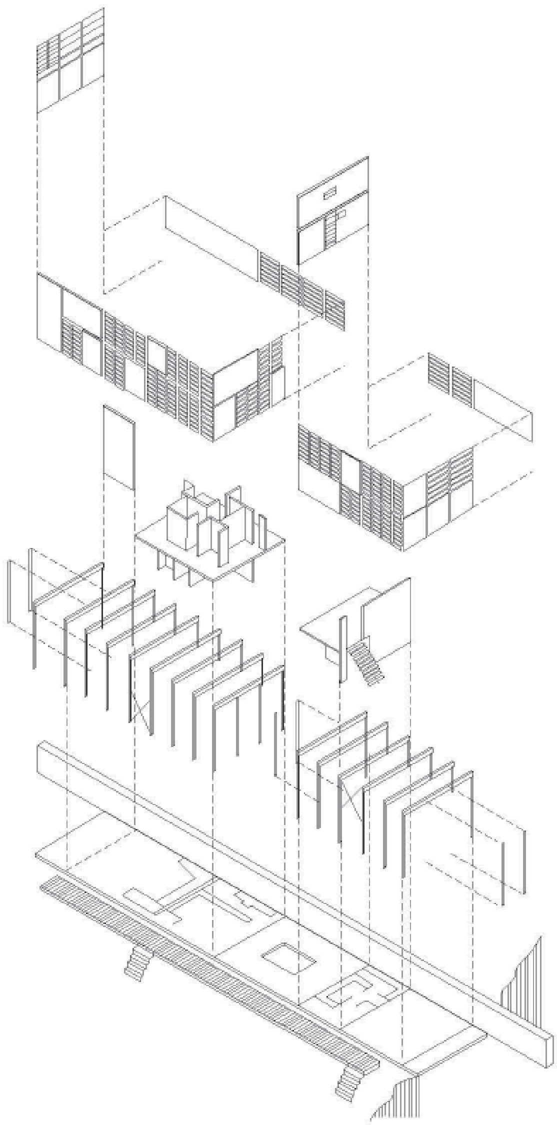


Figure 2.14 Eames House. CSH #8.Construction Components. Exploded axonometric

10 DETAIL Components and Systems: Modular Construction, Design Structure New Technologies, Birkhaüser, Munich, May 2008

Figure 2.15 Balloon Frame building. 1907

FRAME. This system is an element-based system composed mainly by *linear building elements* such as columns and beams that form a structural skeleton. To provide stability bracing elements or special joints are required for the encounter of each group of elements so they are capable of withstanding vertical and horizontal loads. In this case, structural elements are functionally separated from secondary components used as external envelope or internal fit-out.

All non-structural elements as enclosures shall be constituted by lightweight systems that perform as infill walls, floors and roofs or even off-site manufactured room units that occupy the spaces left by the frame structure. Detail design phase is crucial in order to define the nature of the connections and its attributes, so its performance and appearance is correctly integrated to the whole structure design.

In order to be considered a modular system, it must be subordinated to a modular master grid where a unit of measure governs the whole, also it must offer distribution flexibility, showing freedom of spatial configurations by multiple arrangement options.

Pillars and columns must take place following a regular rhythm and enclosure is regulated by the distance between them. Its mandatory that elements involved in this type of construction, must fit –no exceptions allowed- into the main frame, with both components and joints strictly coordinated.

The Finish Moduli 225 system (1968), represents perfectly the features of a modular frame construction system, complying with a modularized floor plan design and offering flexible exchangeable building elements, fully conceived as a system that favors the adaptation in place and time.

PANEL. Panel systems are positioned in the middle range of standard prefabrication and assembly on-site. Panels are supposed to be mostly manufactured in factory while assembly and finishing is to be done on the construction site. Materiality involved can be steel, timber, concrete or masonry, among others.

The construction structure in a panel system consists of *planar walls and slab* manufactured as self-supporting elements, which by addition form enclosed spaces.

Panelized construction conceived as a modular system should combine the design of the primary elements with the general proportions given by a master grid that subordinates the whole. Closing elements in this case, are designed to be structural as well as they solve the envelope. They must comply with being both load-bearing and lightweight so they can be easily interchangeable.

This type of system is mostly about the design of a rich variety of components –panels- disregarding the material used, that satisfy the requirements of the envelope designed to guarantee the quality of the inner living spaces and add also the possibility of transformation, exchange and addition.

The building procedures depend directly on the dimensions and weight of the panels, which are also conditioned by the material chosen. Also, this determine the transport and lifting conditions. Assembly requirements are dependent on the design of the joints and the qualification of the workforce.

All these issues where taken into account in the development of Wachsmann and Gropius' design of the Packaged House. The elements and joints were carefully conceived to create a system by other refined and open to their fullest potential.

Walter Gropius called for a large "construction kit were dependent upon the number and individual needs of the occupants, different living machines can be put together" and "a house of variable elements that are manufactured in advance and can be combined and joined together much in the manner of a large construction kit."

Nerdinger: Walter Gropius 1985-1996, pg. 15

Figure 2.176 Jean Prouvé. Maison Demountable 8x8. 1945

Figure 2.17 Arne Jacobsen. Kubleflex. 1969

ROOM UNIT. Concerning prefabricated systems, this particular type consisting in three-dimensional off-site manufacturing units which are then connected to each other on site, need a more thorough analysis.

Many visionary architectural designs were born in the past mid century. The principles hidden within these designs happen to be the closest approach to the conception of modularity. They were mostly based on standard size components and the use of new industrial materials that create room modules that could be simply interconnected so the units could be removed, added or interchanged as desired.

The adaptability proposed in these systems, in combination with the use of new materials was considered to be trend setting within the construction industry and simultaneously, faithfully represented the progressive vision of a future of mobile and temporary domestic architecture which was dominant at that time.

Currently, room unit systems are meant to be industrially manufactured under high quality standards and excellent performance. Assemblage off-site assures better control over execution and allows strict previous testing of the product. Quality control is higher when tasks are performed in bounded environments by serialized work carried out by highly qualified staff. But some considerations have to be taken into account.

As said before, an inaccurate use of the term is found in some texts. The following excerpt found in the book '*Prefabricated Systems. Principles of construction*', deserves full attention: "Since the advent of modern prefabrication, modular building no longer refers only to the practice of building to a standard dimensional module, but also to the prefabrication of a volumetric building unit. Modules are tree-dimensional independent units or partially complete sections. They can be repeated by stacking or joining side by side in order to extend spaces. The module is the most complete form of prefabrication".[11]

This statement deserves a pause to discuss the idea behind it. In this specific case, the description made of modular systems totally escapes of the very roots of the 'modular' concept that we try to demonstrate, but it has to be noticed that this corresponds to a contemporary widespread denomination.

This description about being just independent dimensional units, almost entirely built in factories under strict quality controls, which are transported completely assembled to be connected in place, shouldn't respond by default to what we understand as a 'modular design'. It is understood that each unit can be identified as a module of a larger building but this not actually have to be interpreted as being part of a modular system.

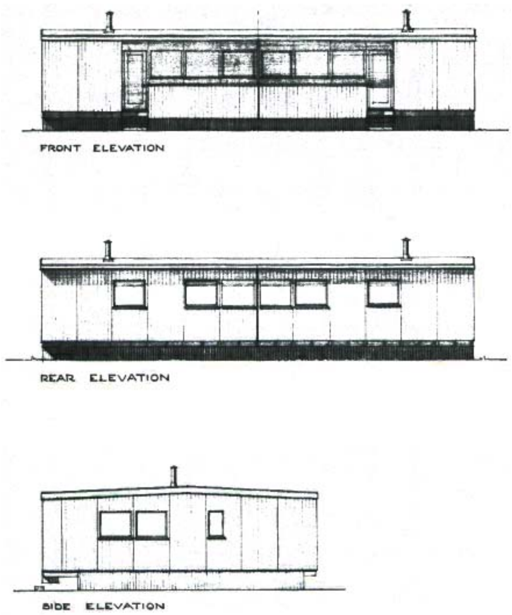
It's mandatory to first analyze the geometry of the units and the latching system, the space generated among the room units in order to determine if the system meets the basic requirements to comply with the concept of modularity. In spite of the strict syntactic analysis, *room unit systems* represent the three dimensional and most complete version of all prefabricated construction systems. Besides having the highest grade of prefabrication and technical control of all systems, they include the more complex design process. The project might integrate all the constitutive parts and outer/inner layers in the same stage, off-site and under strict quality controls. It is also necessary to specially consider the implications of the coordination of installation systems, transportation and placing on site.

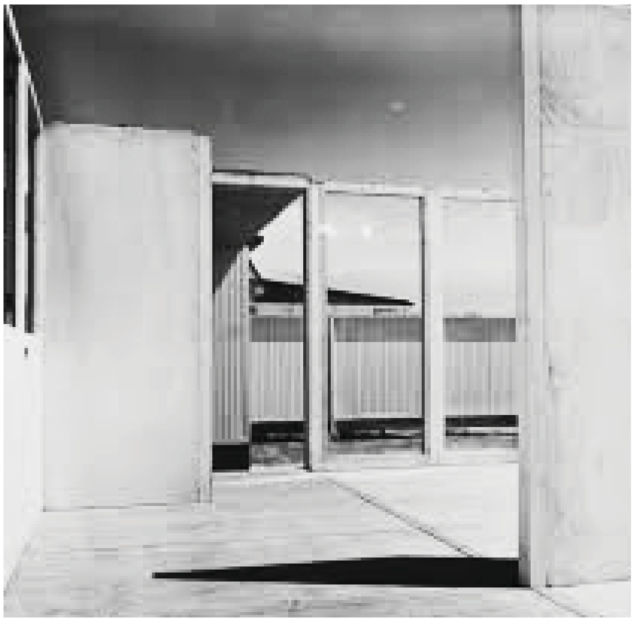
11 KNAACK, CHUNG KLATTE, HASSELBACH, Prefabricated Systems: Principles of construction, Birkhauser, Berlin, 2012, pg 48.

Figure 2.18 Moshe Safdie. Habitat 67. 1967

Figure 2.19 Frame prefabricated systems
A. Craig Ellwood. Case Study House #16. 1951
B. Gullichsen-Pallasma. System Moduli 225. 1968
C. Charles & Ray Eames. Case Study House #8. 1949

Figure 2.20 Panel prefabricated systems
A. Marcel Breuer. Yankee Portable project. 1942
B. Gropius-Wachsmann. The Packaged House. 1941
C. Jean Prouvé. Meudon Houses. 1950





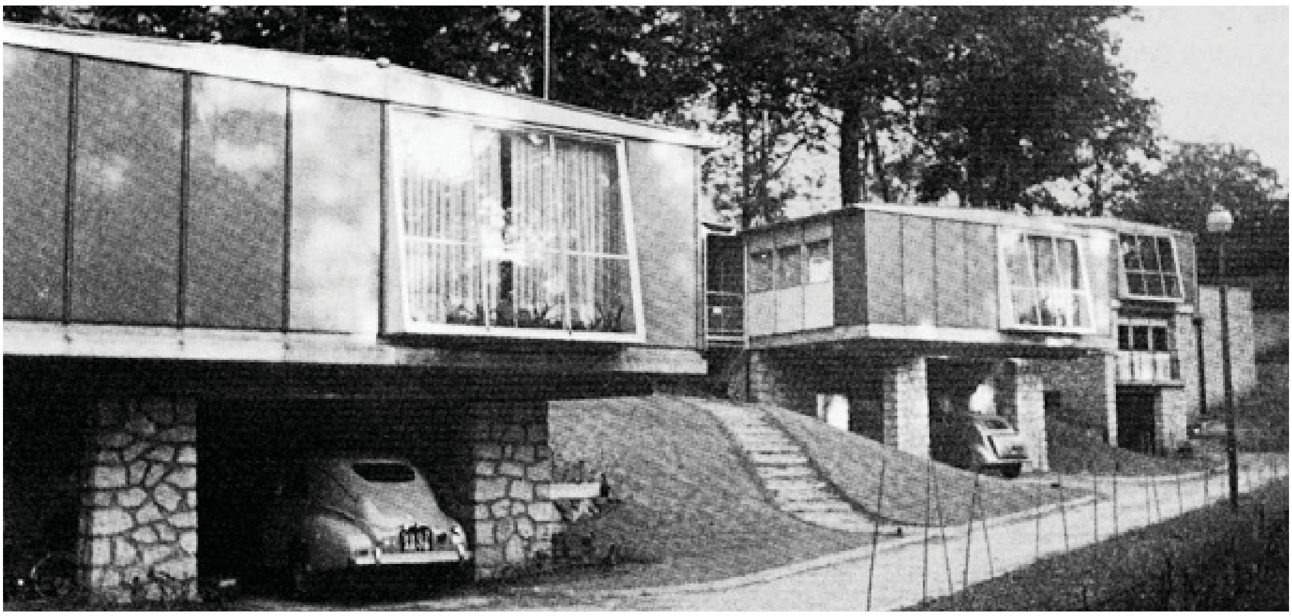
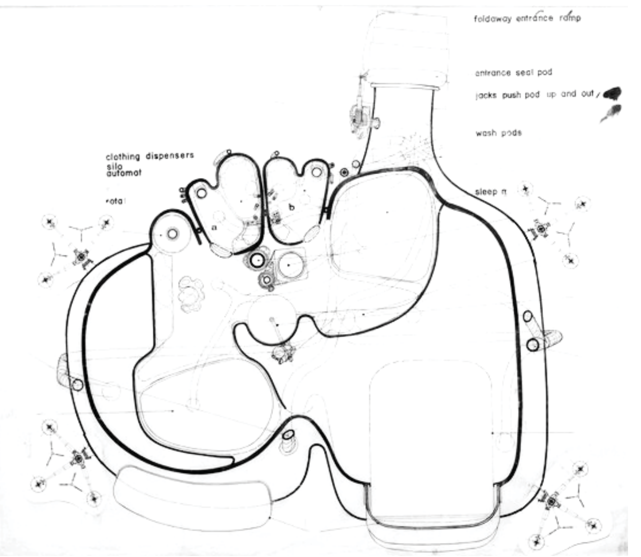


Figure 2.21 Room units prefabricated systems
A. Archigram. Living Pod. 1966
B. Georges Candilis & Anja Blomstedt. L Hexacube. 1968
C. Paul Rudolph. Oriental Masonic Gardens. 1970



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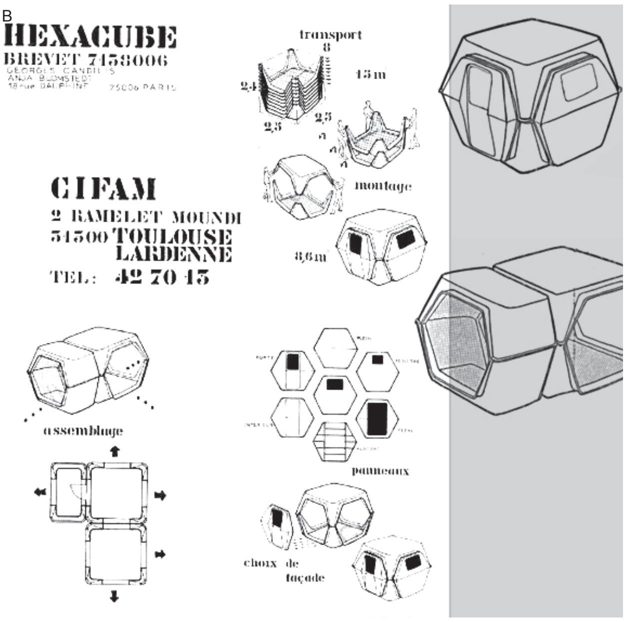

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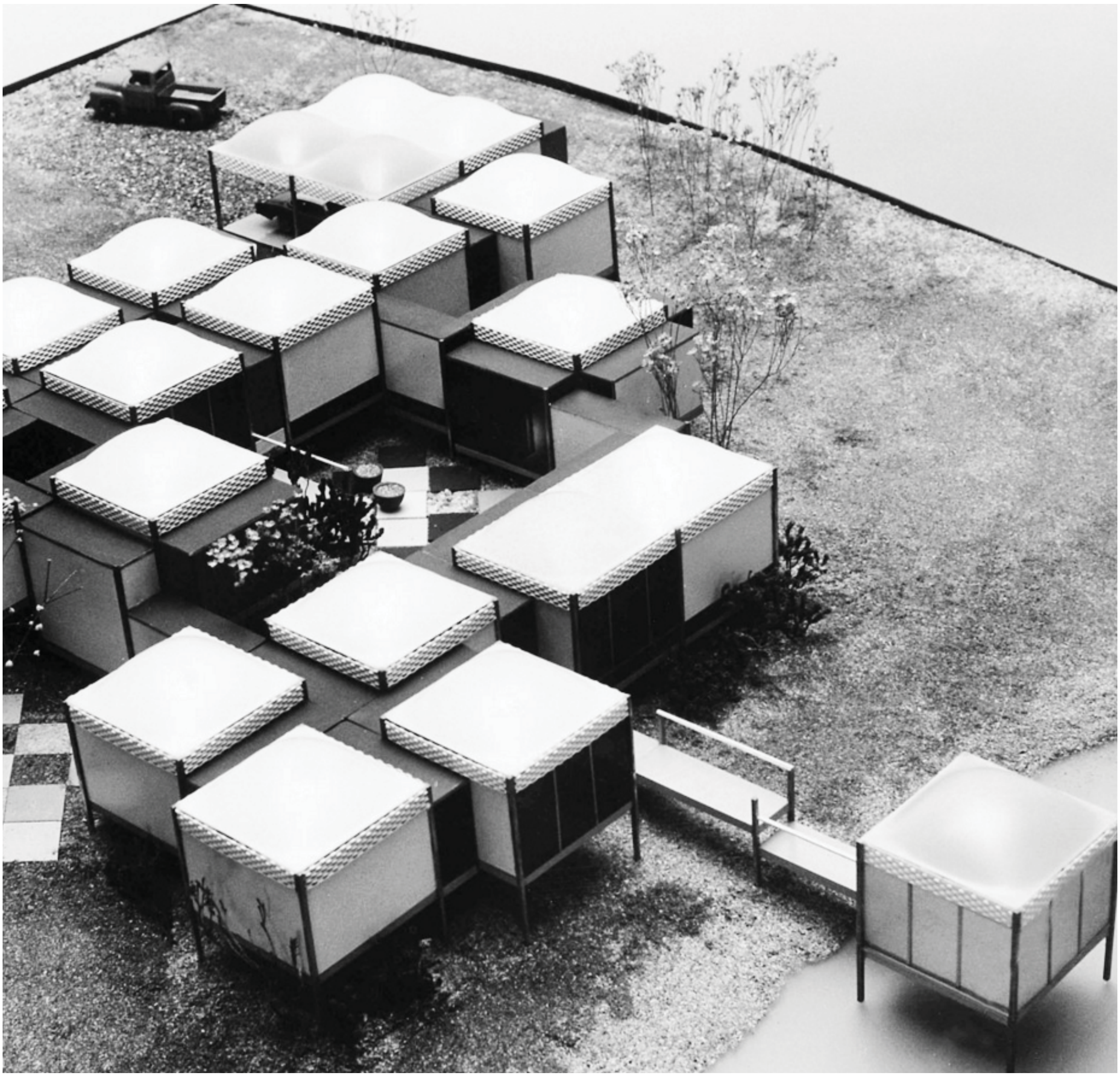
Figure 2.22 George Nelson. Experimental House. 1957



3. CASE STUDIES

The following chapter will be devoted to study three significant cases in the history of architecture, through which will be possible to make a full review the most important features of modular systems.

The selection of the examples was made after a general overview of multiple cases of prefabricated systems developed during the past century. The classification was simply based on the review of the nature of these systems mainly focusing on its constituent aspects: morphology, components' design, systematization of building processes, general aesthetics and even more, in the conceptual baggage that sustains it.

Many architects have attempted to go down the path of design of prefabricated systems and a few have delved on the concept of modularity, having developed systems that at some point manage to depict its intrinsic qualities. As seen before, modular systems must comply with very strict rules and structures that affect each of the stages of design. But going beyond the restrictions imposed on the design process, the concept itself involves other aspects of greater depth that are possible to be found in some specific examples.

The purpose is to establish a classification criteria to help determine the degree of modularity of the prefabricated systems, which are being judged by certain characteristics to a greater or lesser degree that must be unfailingly present in the architectural design of the architectural product.

The cases discussed below, each manages to exemplify in their best way, the fundamental aspects under question, being stronger in one or the other, serving as reference points to determine a standard of qualification.

The space indeterminacy and its degree of design flexibility, the systematization of components and construction processes, and the adaptability to future changes both in use and in form, are the properties that modular systems architecture must meet.

The Moduli 225, The Packaged House and the Espansiva systems, were conceived along with the testing of solid architectural theories. They were designed under strict control parameters and manufactured according to the highest quality standards, resulting in systems other outstanding among the overall of his contemporaries.

The architects in charge devoted decades of their professional and academic lives on these theories that largely exceeded the strictly architectural environment, which naturally decanted into products shortly tested but charged with very high conceptual values. Pallasmaa, Gullichsen, Gropius, Wachsmann and Utzon all form a group of renowned professionals who left an extraordinary legacy still in force. The successes and failures of their proposals are not conditioned by their more or less respectable ideas, but the maturity of the consumers' market and the technological advances available in those decades, did not certainly accompanied their avant-garde ideas.

However, they managed to stand out to get away from their contexts and stay advanced in time, being still respected and constantly reviewed.

Modular systems in architecture may be characterized for multiple properties but the ones that will be developed below demonstrated to be those that best explain and complete the concept at every level.

3.1 UNIVERSALITY

Spatial conformation and absolute aesthetics approach.
The search for a universal design: Moduli 225 System.

3.1.1 INDETERMINACY. Modularity, speaking in terms of planning, implies a design process that goes for abstract forms. This achievement involves the inclusion of certain protocols that lead to universal, and simultaneously unique architectural products.

The systematization of the design process plays a key role; the evolution of technology applied to the manufacturing of building systems is essential but more important is the conceptual exploration involved in the planning of these designs.

Modulation, standardization, systematization, coordination, openness, flexibility and customization are the main features associated with the design of modular systems seeking to be universal and absolute. A modular system is by default, abstract and generic enough that proves to be both adaptable to the costumer and to the environmental circumstances.

Spatial indeterminacy is the most valued and harder to achieve feature. The subdivision into equal portions able to house any function and its capacity of easy conversion claims for a very precise design.

What emerges from this is that the existence of a hierarchical structure it's mandatory, as well as a set of rules that master the process which takes to results that are varied but generic. As said before, it must be based on one unit of measurement that sets on a regular grid which defines the pace. It must encourage the systematization of all the phases -design, manufacture and assembly-, and should also include a precise coordination of all parts providing a big grade of flexibility and openness to change.

The resulting aesthetics will be absolutely controlled, managing to be impersonal and at the same time unpredictable. The resulting language will be free of authorship which is a key feature of these systems, always tending to anonymity and leading the users find the expression that fits more to personal needs and tastes.

Having already reviewed some associations of the term 'modular', what follows is the attempt to delve into some architectural examples which help enlarge the concept. They were chosen for being further analyzed strictly based on its own approach to modularity and for the contributions made to the evolution of architectural design and prefabrication techniques.

Since modernity, a widespread international movement devoted to the industrialization and the functionalism of the machine, set the eye on simplifying the domestic architecture. Exponents as Le Corbusier and representatives from the Bauhaus, widely experienced in simplifying architectural products to respond to a massive need of the time. Post-war years encouraged great thinkers to develop projects and prototypes seeking indeterminacy, economy and speed of execution.

Universal proportions systems -Le Corbusier's Modulor, Blomstedt's Canon 60- were developed and reinterpreted again and again, in the search for objective rules and abstract guides that support system designs. The first attempts made in the early twentieth century decanted into futuristic and utopic proposals, while in the 60s other referents emerged that based their ideas on the same trends focusing this time on more realistic and moderate solutions with a high degree of objectivity.

Within the core of the Finnish intellectual environment, a group young architects experimented with cutting edge designs of the highest quality, great refinement and excellent manufacturing.

Figure 3.1.1 Moduli 225 system. Industrial summer house model. 1969-1971

3.1.2 CONTRIBUTIONS. Great contributions were made by many well-known architectural references doomed to design, development and commercialization of prefabricated modular systems. There have been several characters who ventured into these matters and made much progress in various fields. The so far revised concepts, made in an abstract and theoretical way, deserve to be at once exemplified.

One of the most prominent examples in matters of prefabricated modular systems, was conceived within a very important architectural movement of the last century. Advanced in time and based on several previous achievements, the *Moduli 225 system*, designed by the young Finnish architects Juhani Pallasmaa and Kristian Gullichsen in the late 60s, represent one of the purest and sophisticated designs ever made.

This example, within a very wide range of prefabricated systems ever developed, turned to be absolutely exquisite, conceptually consistent and powered by the most refined design. These explorations made along the 20th century left great advances not only in the architectural environment but also in the construction field, but what the Moduli 225 tend to represent is what the most rigorous modular design aimed to achieve.

Being consciously abstract and ruled by a very precise set of orders, this system reaches the purest state of absolute and universal architectural design, being at the same time, very successful at representing the concepts related to modularity explained so far.

Universality, abstraction, absolutism and indeterminacy are the main features that the Moduli 225 provides to this review of modular systems.

FINNISH CONSTRUCTIVISM. During the 60s, Finland went through significant economic and social changes having overcome the material austerity suffered during the WWII years. The country prospered rapidly and a new industrial era started, transforming seriously the building traditional environment and architecture moved also to serial production lines.

The increasing prosperity and the social welfare state enlarged the demand for new public institutional equipment and solutions for domestic architecture and private recreational spaces. The established generation of well-known finish architects was in charge of the renovation of the image of the cities being commissioned to design large master pieces that showed with their own particular signature.

A younger generation of students and architects began to question the work, ideas and reputation of these recognized characters -among which was the highly revered Alvar Aalto- for being considered individualist, subjective and romantic. The atmosphere of general radicalization based on a new vision of social sciences that reigned in the 60s, also called for a solution based on the anonymous, absolute and universal architectural proportional systems rather than the idea of individual works of art.[12]

The Finish architectural design reached a turning point and claimed for a comeback to the original functionalism preached by the Modern Movement, based on the Japanese simplicity and Mies Van der Rohe paradigms. Pallasmaa, Mikkola and Gullichsen represented the flagships of a new generation that called for a return to orthogonal structural grids, undetermined, open and flexible spaces and common expression based on transparency and simplicity.

12 TUOMI, Timo, Aspects of the 1960s: Architecture as Social Activity and Art-form in FINLAND 20th Century Architecture, Norri , Marja-Riitta, Standertskjöld, Elina and Wang, Wilfried (eds), Helsinki, 2000, pg 99.

Figure 3.1.2 Moduli 225 system. Summer house in Finland. 1969

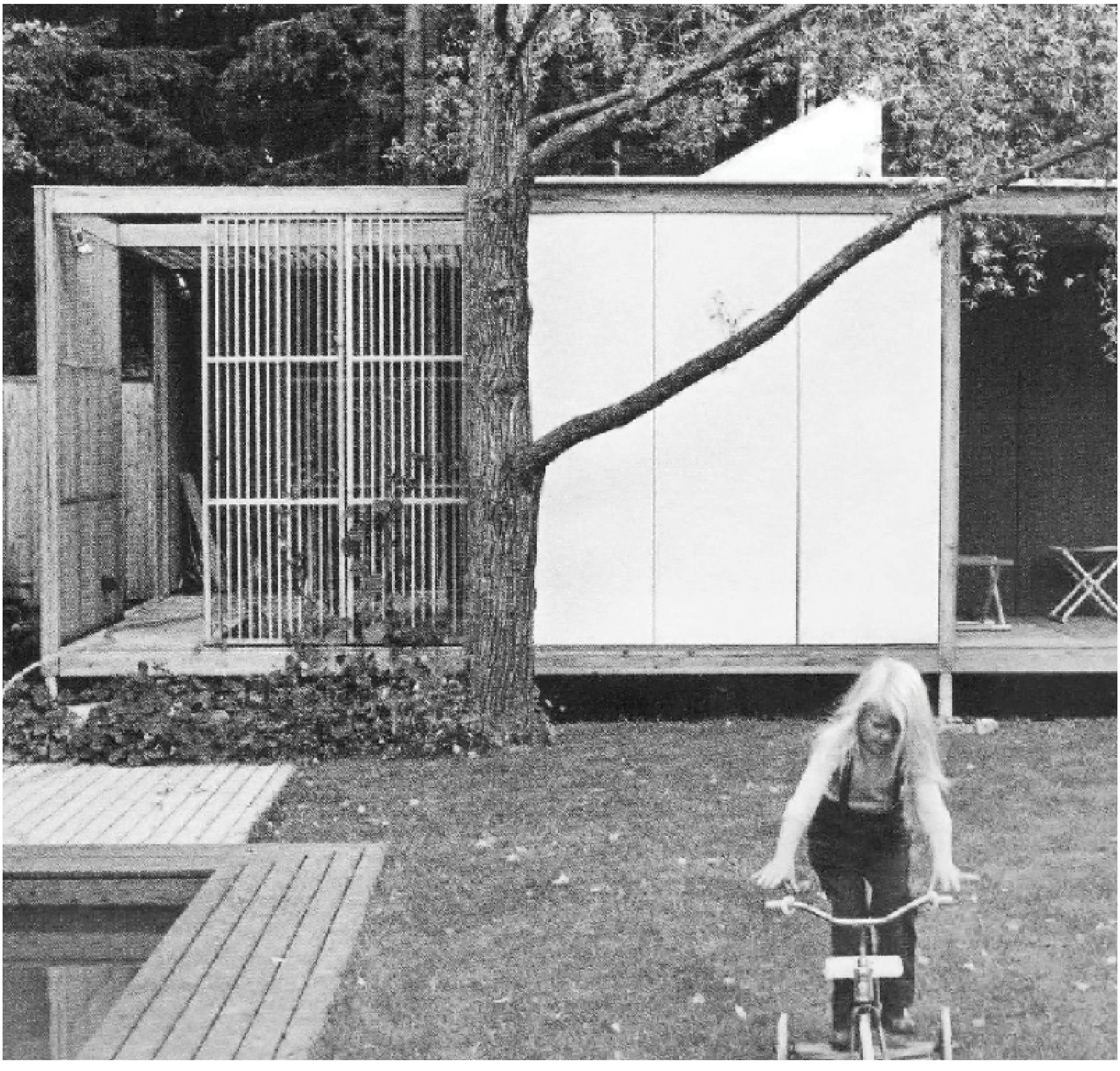


Figure 3.1.3 Moduli 225 system. Fluid connection between spaces. 1968

3.1.3 ABSOLUTE ARCHITECTURE. The sought expressions of this architecture lean towards the essentiallity and abstraction, both in conception and form. The design of regular and mostly cubic structures, carefully modulated and rectified, reflected the search for a homogeneous, light and open attitude towards the current social situation.

Many were the influences that caused this shift, but the general attitude towards revising the dictates of the contemporary architecture was experienced as a confrontation between opposites: general vs. special, anonymity vs. subjectivity, structure vs. sculpture, social vocation versus elitism.'[13]

From Japanese traditional architecture they took the notion of abstract composition based on a module taken from the human dimensions (ken), the clean aesthetics and fluent continuous spaces. The lightness and openness gave a predominant role to the relationship with the nature.

This absolute architecture that they search for was commanded by very precise geometries based on open incorruptible structural grids that left generic inner voids to be filled or be subordinated by the natural context. The neutral framework created the conditions for maximum interior flexibility and expressed a clear preference for open spaces.

The interiors were totally commanded by the inhabitant, who played the main role adjusting and customizing the homogeneous non-hierarchical spaces in order to fulfill his needs. The architecture became a simple container, where the equipment was reduced to the minimum needed and the combination of materials were the once which gave freedom to the building the aesthetics.

For succeeding in the manufacturing process of this essential architecture, constructive precision and execution control were mandatory. Very elaborated and revised construction details, precisely executed and assembled on site, were the key for reaching the so desired absolute architecture. Only a very experienced industry in this field and predisposed to innovate and improve the techniques could respond to these requests.[14]

Previous and outstanding progress made in the field of prefabricated construction was fundamental for the development of these new architectural concepts. The refinement of construction techniques and the industrial manufacture of new products such as laminated wood elements and chipboards, allowed extremely detailed and sophisticated designs.

Wood and its manufactured sub products offered dimensional stability and regularity, with coefficients tolerances, favoring the development of extremely refined details. The lightness, low cost and ease of assembly made these products totally appropriated in that era in which efficiency and speed were highly valued. The excellent thermal behavior of this material was decisive in being chosen as the most appropriate for this type of architecture, being more efficient than steel and concrete in preventing thermal bridges, a quality highly valued in such extreme climates.

The achievements made by the Finnish Constructivism movement in the design field, are based in the internationalization of architectural forms and it building processes which strongly defended its exponents.

The Finnish movement advocated for an *absolute architecture* based on universal procedures and harmonic compositions, aligned with the industrial and standardized building processes.

13, 14 RODRIGUEZ, Jairo: INSTANTES VELADOS, ESCENAS RETENIDAS. Pequeña escala en la arquitectura finlandesa en el siglo XX: villas, residencies y saunas. Valladolid University, 2013, pg 255.-References taken and translated from the Doctoral Thesis-

Figure 3.1.4 Aarno Ruusuvuori. Marimekko sauna.1969

BACKGROUND. The main references might be sought in the international context at the beginning of the 20th century. The production line of the automobile invented by Henry Ford motivated the simulation of these processes in the field of residential architecture.

Le Corbusier also encouraged this idea few years later, with his design of the “Do-mino” system that called for the idea of a house-machine. Gropuis, at the same time, argued that if people were willing to use industrial fabricated shoes, also should this concept be applied to housing manufacturing.

The concept of customization was introduced by Le Corbusier, who designed by 1929 a system of combinable and stackable modules, together with numerous prefabricated dry-assembly homes experiments carried out in Germany, France and the United States simultaneously. Breuer’s Yankees Portables and Wachsmann-Gropius’ Packaged House were highly publicized and revered by mid-century and reviewed as part of the most important achievements of this era.

America was fascinated by the freedom of expression achieved by the industrial design applied to domestic life. The Case Study Houses program that took place in California in 1945, driven by John Entenza, hypnotized the whole world. The proposals of prefabricated houses made entirely by standard products found in commercial catalogs, achieved highly innovative solutions and cutting-edge designs, which were taken as an example and replicated worldwide.[15]

Its module-based design, the prominent role given to the material development, the search for a general and neutral aesthetic and the essentiality of the space, were the result of a whole movement that called for a refreshment of the domestic architecture culture and left a legacy filled with examples worth admiring.

In Finland, during the late 1960s, a multiplicity of serial production ‘light building systems’ were designed for single family houses based on wooden elements and universal dimensions, with the aim of allowing spatial variations within the orthogonal framework.

“An example of experiments based on modular systems was the Moduli 225 building by Kristian Gullichsen and Juhani Pallasmaa which, with perhaps greater refinement that many others corresponding experiments, combined Finish timber, a universal module and a Japanese-inspired elegance.’[16]

In 1968 and after big debates and great changes in the industrial field, the A. Ahlström Corporation commissioned Gullischen and Pallasmaa to develop a single-family system that raises the value of processed timber which had been relegated by the use of new industrial materials such as steel and molded concrete.

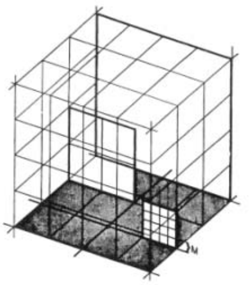
The wooden construction system Moduli 225 was an attempt to create a housing construction system made up entirely of industrially produced construction components that would allow optimal freedom of variations. The aim was to develop systematized processes that end up in standardized architectural objects, changing rapidly from individualized and independent to universal and generic proposals.[17]

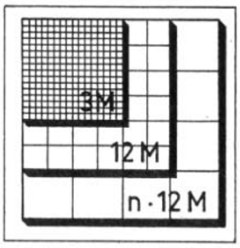
The results of the co-working between Finnish industrials and young architects related to the Constructivism movement were more open designs, flexible and aesthetically more attractive than previous experiments and building systems detailed to the extreme of the possibilities, being both simple and refined at the same time.

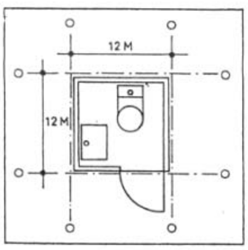
15 RODRIGUEZ, Jairo: INSTANTES VELADOS, ESCENAS RETENIDAS. Pequeña escala en la arquitectura finlandesa en el siglo XX: villas, residencies y saunas. Valladolid University, 2013, pg 254-248 -References taken and translated from the Doctoral Thesis-
16 TUOMI, Timo, Aspects of the 1960s: Architecture as Social Activity and Art-form in FINLAND 20th Century
17 SOUMEN Rakennustaiteen Museum of Finnish Architecture, Timber Construction in Finland,1996.

Figure 3.1.5
A. BES SYSTEM, Smallest room space component,
B. DOMINO SYSTEM. Raimo Kallio-Mannila 1968
C. MODULI 225 SYSTEM. Pallasmaa-Gullichsen 1968
D. MARISAUNA. Aarno Ruusuvuori for Marimekko1968

A







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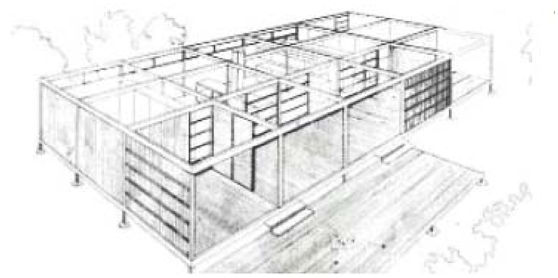

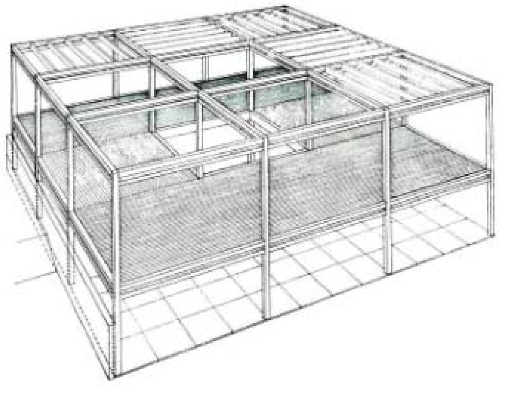

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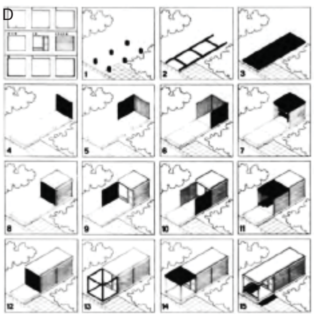
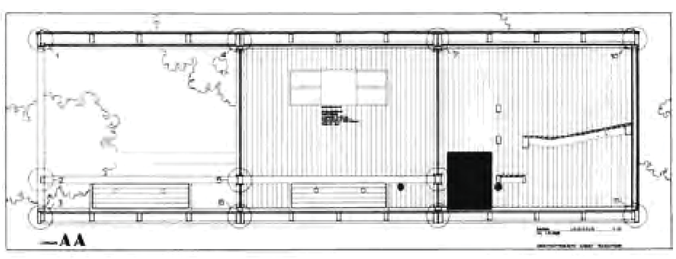


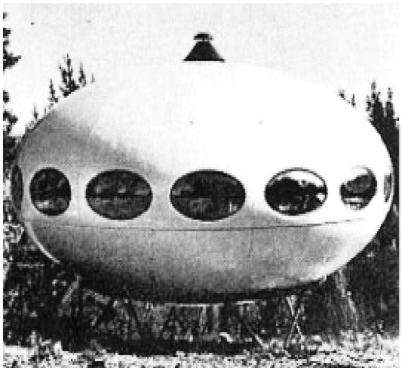


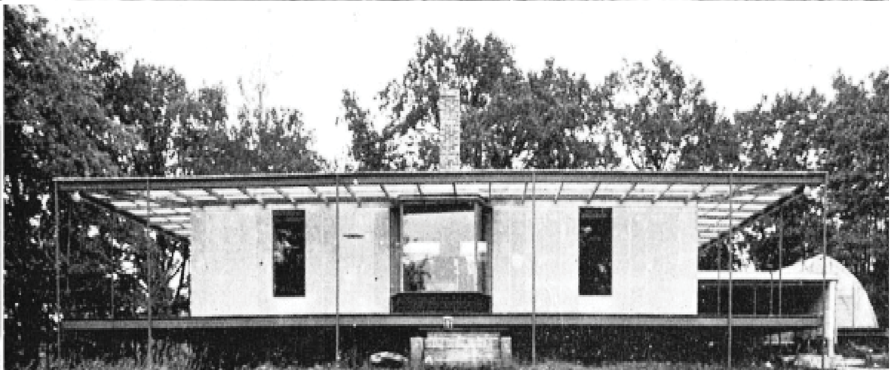
The housing solutions developed in Finland between industry and architects were more open, flexible and perhaps aesthetically more attractive than previous ones. They were known as light systems and appeared as a natural y final progression of the ruling wooden constructivism. These light systems were defined based upon modular construction methods -like a Meccano- were presented unassembled and entirely prefabricated.

RODRIGUEZ, Jairo, PHD Thesis. INSTANTES VELADOS, ESCENAS RETENIDAS.
Pequeña escala en la arquitectura finlandesa en el siglo XX, pg. 287

E. ARKKITEHTI magazine. Single-family and summer houses between 1964-1973
-Matti Suuronen's Futuro House 1968 cutting edge portable kit, among them-
F. AS-YOU-WHISH Modular System. Juhani Vainio, Pentti Lehtinen. Espoo 1968
G. DOMINO SYSTEM. Raimo Kallio-mannila. House by Eero Valjakka. Helsinki 1968

E





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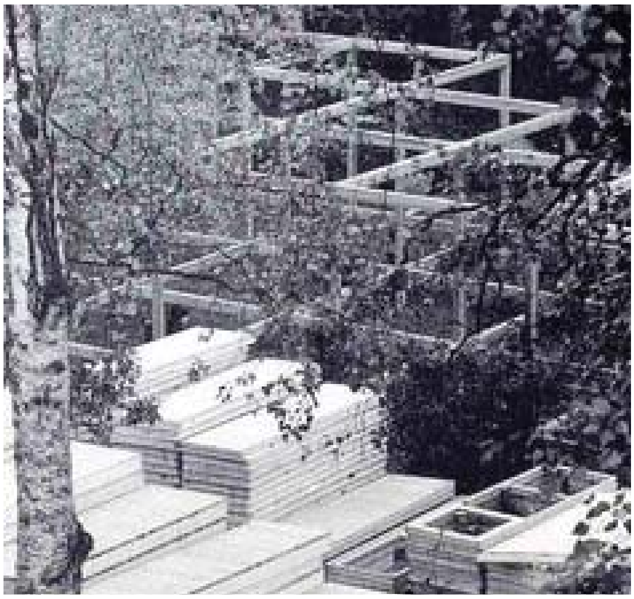


Figure 3.1.6 Moduli 225 system. Frame structure and panels

3.1.4 SYSTEM MODULI 225. Architecturally, the system is an adaptation of the modular Japanese tradition of timber building, and a demonstration of its timeless universality.[18]

Not only the floor plan distribution could be freely chosen by demand but also the external appearance and the roof form could be selected by the customer preferences. Its variety of configurations and the capability of being assembled with no needs of tools gave the system a universal character and immediate acceptance. Not only construction methods but also spatial distribution was taken into the limits of the modularization process, where the efforts were put in developing open unit arrangements and superior building systems.

Taking its name from the use of a single module measuring 225 centimeters in each of its cubic dimensions, the house contained within the regular grid, could be configured in an almost infinite number of combinations. The 225 measure was taken from Aulis Blomstedt modular fraction developed in his 'Canon 60', and very similar to the very well-known 226 cm module proposed by Le Corbusier in his 'Modulor'.

The whole system was conceived to respond to the Finnish extreme weather solving all the meetings by elastic joints, and reduced to only 17 types of building components, 13 of them were combinations of vertical panels for the external envelope. All the elements arrived ready to the site and were able to be assembled and unmounted on site in just a few days by workmen and none of them would exceed the fifty kilograms.

Each space frame module has tree vertical or horizontal equal divisions measuring 75 x 225 cm, which allow panels to be inserted on any given side-fully glazed panels, opaque panels, slotted panels, doors panels, or the absence of infill altogether.[19] The panels were exchangeable, offering the system multiple possible combinations.

The rest of the components were given to the structure and ground supports. Beams and pillars were all equal; pillars were designed based on a square section of 9.2 x 9.2 cm and beams on a rectangular section of 9.2 x 15.5 cm. The joints between these elements, apart from being elastic, were solved by aluminum connectors hiding in the faces of the elements within gutters staying protected from weather and an eventual burning.

The panels fit within the structural frame and fixed to the lineal elements in any position, stiffening the whole structure. The union between the building and the ground was solved by a very particular piece that responded to any terrain condition, eliminating the need to excavate to level the plot to prepare the foundations for this aim. These adjustable stout metal pylons allowed the regulation of the height until 1.5 meters in each support, giving the system the ability to float slightly above the ground plane.

The roof was solved by two layers of horizontal panels leaving a free space above the false ceiling where the electrical installations and heating ran. The system also offered the possibility of inserting skylight prefabricated elements that fitted into the regular grid. The flat roof panels that support the waterproof sheet are compound elements made of wooden boards on both sides and insulation between them, also showing a lateral reinforcement between boards through a solid piece of wood.

18 NORRI, Marja-Riitta, Standertskjöld, Elina and Wang, Wilfried (eds), FINLAND 20th Century Architecture Helsinki, Museum of Finnish Architecture, Helsinki, 2000, pg 248.
19 BERGDOLL, Barry, CHRISTENSEN, Peter, HOME DELIVERY: Fabricating the modern dwelling, Museum of Modern Art - MoMA, New York, 2005, pg 152-153

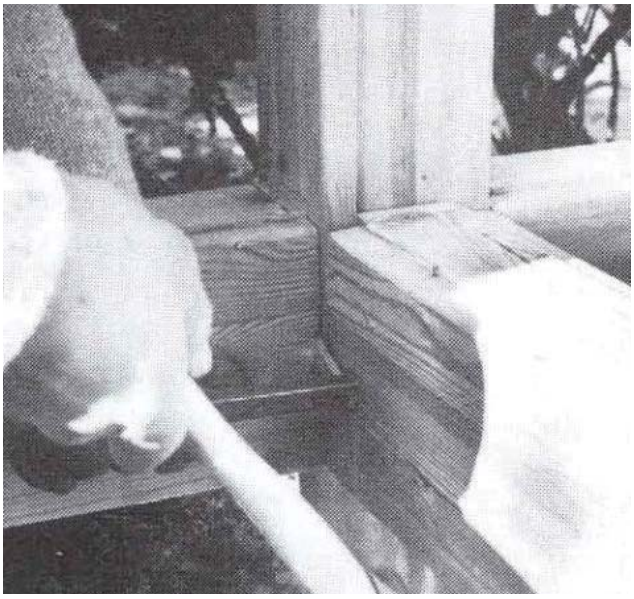


Figure 3.1.7 Moduli 225 system. Assembly process

The support of the ceiling panels is between beams and alternate their placement direction. The difference between the ceiling panel and the wall lies in the dimension of its section increasing in the roof panel.

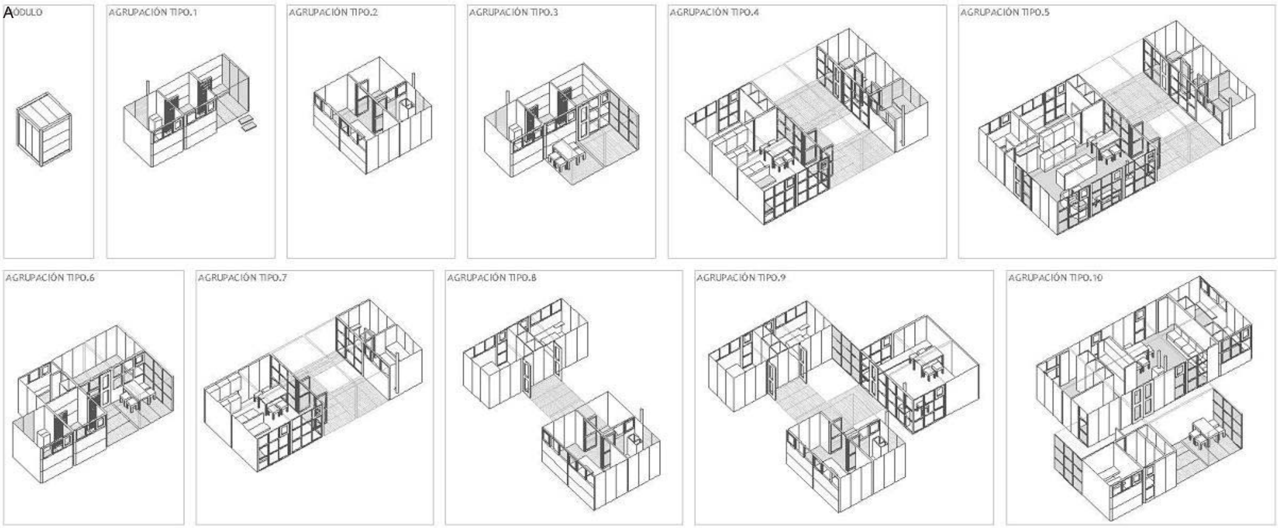
Also, the panels differ in qualities obeying the different requirements: seen or not and weathering resistance or not. The coverage is made with a self protected sheet that elevates on the perimeter over a small triangular end piece and it’s completed with a metal sheet that eliminates the runoff waters from the top part of the panel. These metal pieces contain the waters which are discharged with gargoyles.

Moduli 225, based on an orthogonal modular grid was highly advanced in terms of spatiality. The equal subdivisions of the inner and outer domestic space gave freedom in the floor plan configuration. Although fittings, plumbing and heating had to be taken into consideration in order to serve correctly the domestic requirements, the system managed to provide served hidden spaces to drive facilities.

The ease of assembly and the many enclosure options gave real possibilities of the envelope customization as well as flexibility to interchange inner spaces in demand of the users. However, this expected transformations were not entirely possible because production was discontinued a few years later.

Since 1970 and 1974, at least sixty units of Moduli 225 were sold and built in Finland, Japan, France, Sweden, Norway and the US. In spite of the universal character given in its design, the efforts to publicize it internationally and the reduced selling prices, the system didn’t manage to give Ahlstrom the revenues they expected. The last unit that was built was in 1979 during the Maison de Bois exposition in the Georges Pompidou Center.

Figure 3.1.8
A. System modular arrangements
B. System building elements

A


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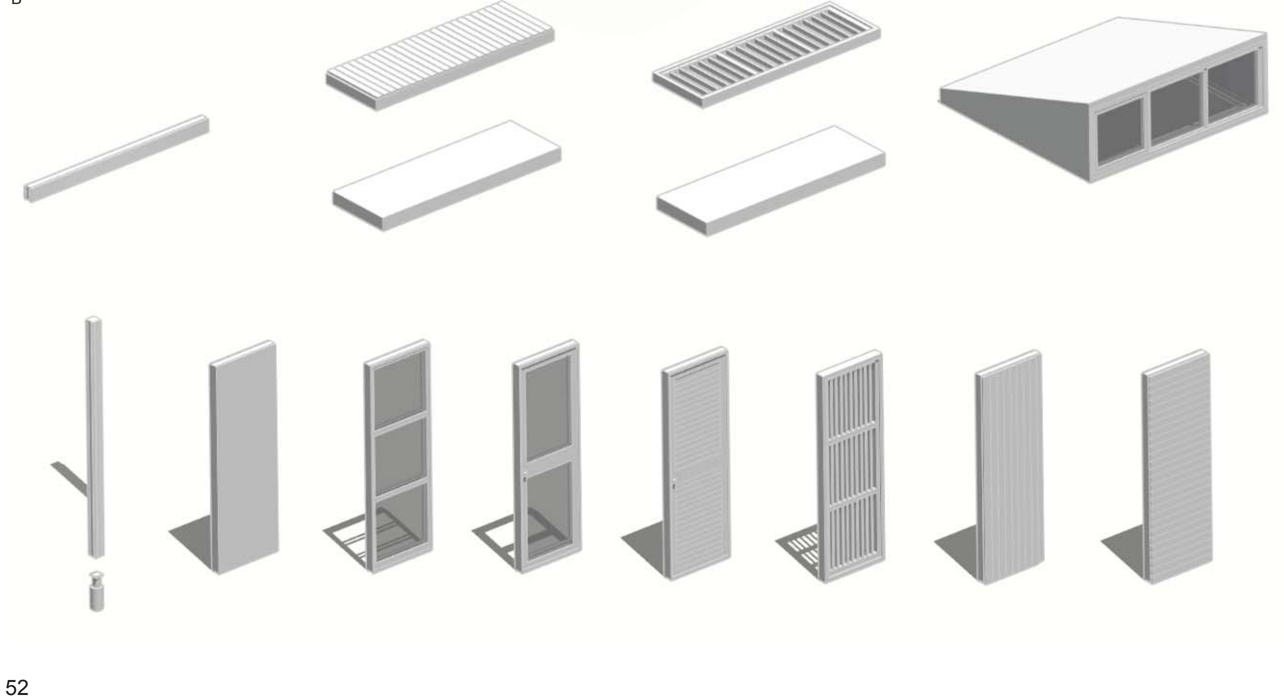
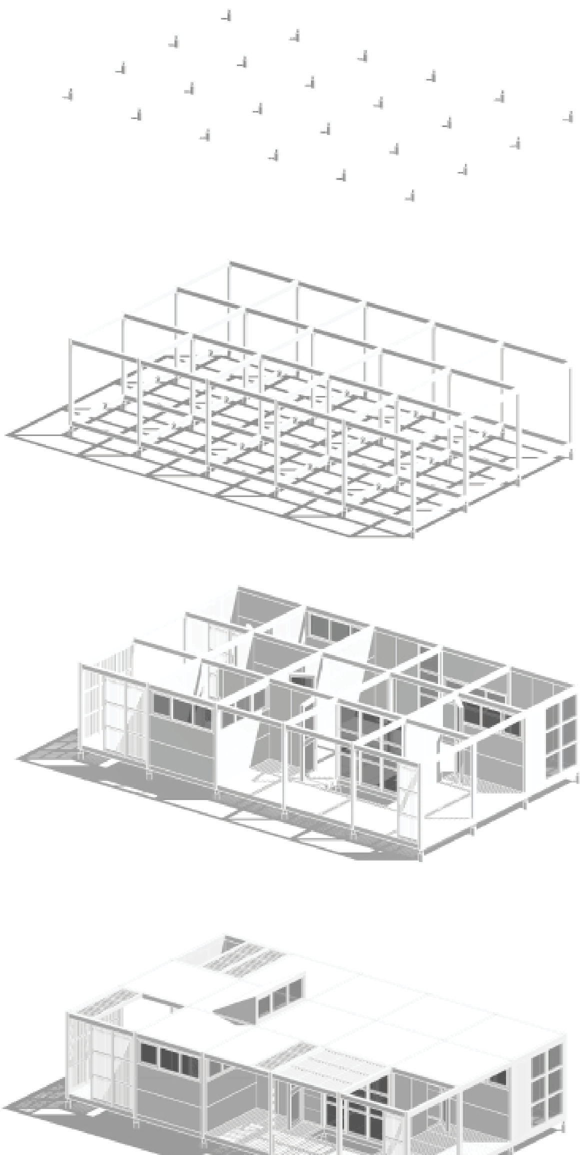


Figure 3.1.9 Moduli 225 system. Outside view

Figure 3.1.10
A. Building process axonometric: Foundation, frame structure, wall panels, roofing
B. Building element joints and foundation solution axonometric
C. Floor plan a built example

A



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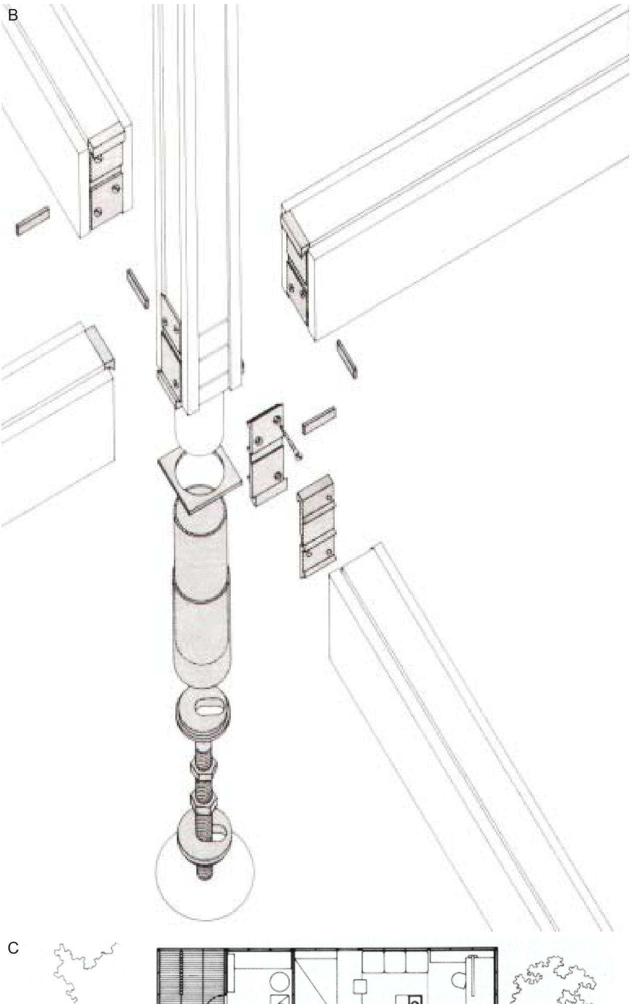


C

Figure 3.1.11 Moduli 225 system. Cover outer spaces

3.2. SYSTEMATIZATION

Building systems genetics approach.
Searching for precision: The Packaged House System.

3.2.1 PROGRESS. The introduction of modularity in the atmosphere of architectural design, leads to the development of an architecture that looks to be *absolute* and *universal.* It's true though, that the introduction a set of rules into a design, more that restricting the process, may end in unexpected results. Modular design show richness of forms, variety of spaces and great amount of flexibility in its configurations. However, the aim is to get to a *systematic* way of thinking and to create a controlled atmosphere where the game is set by the hierarchy of its elements and the conditionals imposed to the connections between elements.

Introducing the notion of *systems,* as a combination of parts forming a complex body may help better describe the processes undergoing in modular design.

In architecture, it refers to the interconnection of elements, processes and information that constitutes the creation of a building; primary and secondary elements are subordinated to the arrangements defined by the set of rules.

Within a system, a module encloses complexity (structure and interaction) as a subset or component within a larger complex system.[20] As a component of a bigger structure, it should minimize the interactions with other elements, being sufficiently autonomous while remaining part of a greater whole which gives it significance. A module that belongs to a modular system is irreducible and can't be subdivided any further, having its own well-defined boundaries.

The systematization of designs was encouraged by the technological advances achieved by the mass-production industrial process. Although designs were being modularized and buildings were being industrialized from the end of the 18th century, it wasn't until the 20s that architects considered the possibility of emulating the industrial process in the building industry. Steel and wooden prefabricated systems, mobile home designs and catalog kits were the first large-scale experiments in prefabricated housing that mostly all of them ended up in failure.

The first postwar industrial development introduced the idea of abandoning the individualized building elements and succumb for standardized measures and components. Modularity was always associated to economy and production matters, so practical issues concerning the savings generated through mass production and social incentives to develop affordable housing fostered the simplification of designs for mass production.

This came to be an ideology that encouraged the standardization of a great variety of building elements, from minor drywall panels to whole complete room units. The systematization of the building industry was a matter of giving response cheaply and quickly to the great demand of singular housing during the postwar years. The effort was put in simplifying the whole processes to get rid of any singularity in order to leave room for systematized, generic and regular designs. Paxton, Le Corbusier, Mies Van der Rohe and the great majority of the modernist adopted the concept of modular design to comply with the mandate of the moment, where the passion for the machines led to the most outstanding designs of that time.

The growing industry and the possibility of standardization of components encouraged architects to the development of building systems that looked for flexible arrangements with future adaptations, introducing the idea of integrally designed systems that gave complete solutions.

20 SALINGAROS, Nikos A, MEHAFFY, Michael W, A Theory of Architecture, Umbau-Verlag Harald Puschel, Germany, 2006

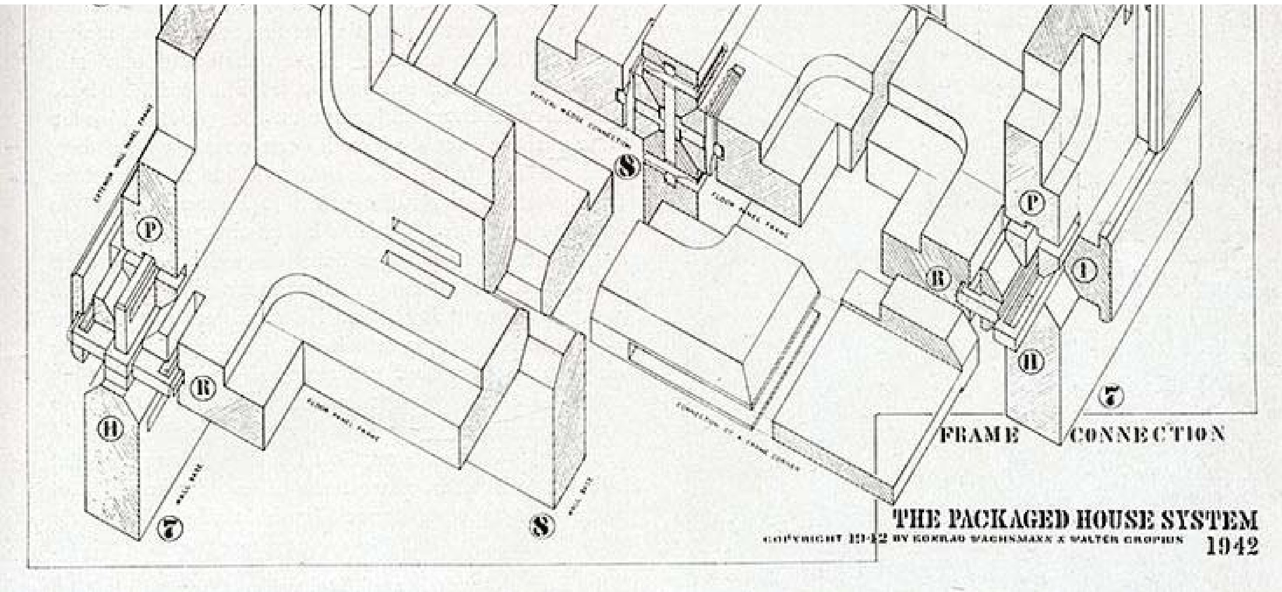


Figure 3.2.1 The Packaged House System. Connection detail. 1942

3.2.2 SYSTEM THEORY. In the past century the achievements made in technology and industrial fabrication were in straight relation with the development of system theory in architecture. Building systems represent directly the conceptual framework of this debate.

During the first decades of the past century, exponents of the international architectural movement that supported the notions concerning functionalism and began to cultivate the idea of an integrated architecture, based on technological advances and absolute devotion to detail.

These men -Fuller, Wachsmann, Gropius- saw the totallity of the whole and the significance of the part as reciprocal aspects of an integrated system.[21]

The concept of 'system' was new at that time being just reviewed by a few theorists. Not only the term wasn't common but also hadn't been applied to the architectural environment. Once the idea had been understood, the system theory of architecture began to spread.

The most comprehensible form of this theory was seen in prefabrication, being a very direct interpretation of it. A prefabricated system embraces a group of components organized hierarchically, and each is both understood as an individual entity and as a part of a whole, governed by a very defined set of rules that allow or not any kind of combination.

It was a model of order and integration, based upon a clear organizing principle.[22] The modern movement rejected the known styles and looked for stability, a framework of control filled with logics to face a whole new era of design.

Prefabrication, modularity and standardization, with its agreed vocabulary of parts and syntax of relationships, appeared to be acceptable[23], being stylistically neutral.

In the paper *An American Wartime Dream: The Packaged House System of Konrad Wachsmann and Walter Gropius*, Alicia Imperiale cites: "System theory was developed in tandem in the biological and physical sciences, challenging the previous held conceptions about organization. According to the laws of thermodynamics, a physical experiment is a 'closed' system, in which a finite set of elements are in interaction and will tend towards a condition of 'entropy' or loss of information as the system advances towards equilibrium. In contrast, argued through a 'system' approach, organic and non-organic phenomena are considered as "open" systems– with interactions back to and from the environment."[24]

This paragraph reinforces the idea of a system being in fact any kind of entity composed of interrelated parts. Each has a structure that determines how the components are arranged and the function that each part performs in the system environment; systems of elements in mutual interaction.

The relation described was attempted to being reproduced on many occasions and multiple were the trials made in the field of building industry in order to achieve a design that did not lose its status as a system and its condition of universal when it had to face the mundane problems of manufacturing.

More than being a set of protocol relations between the parts, a system is also a tight form of organism that doesn't lead to any singularities.

The idea of the house being a product of a wide range of combinations that could generate thousands of designs is yet very tempting, and the concept of the mass production romantic for its own sake.

21, 22, 23 HERBERT Gilbert, The Dream of the Factory-made House, The Massachusetts Institute of Technology, US, 1984, pg 7-8
24 IMPERIALE, Alicia, An American Wartime Dream: The Packaged House System of Konrad Wachsmann and Walter Gropius, Temple University, 2012 ACSA Fall Conference. In this paper the author cites: Bertalanffy, General System Theory, (New York: George Braziller, Inc., 1968), 33-44.

Gropius participates later in several operations in cooperation with industrials. One of the first systems that he developed, dedicated to emergency housing, offered as an introduction to the General Panel System, removed the usual framework to incorporate it into very thin bearing walls. His philosophy was to create a direct plastic result of component assembly, responding to the vital need to live more than responding to a specific aesthetic. Following Gropius, the stranglehold of specialized technicians on components' architecture will motivate numerous architects to develop their own construction systems and leading many of them to bankruptcy. Indeed, the logistics, technical knowledge and planning means necessary for the establishment of a construction system in general were of such magnitude that they did not provide, as part of a large-scale use, to be the fruit of the work of a single individual. So, mechanization of architecture could be the cause of a certain climate insecurity in the architectural spheres of postwar.

T.Schwartz, S.Sadettan, P.Seron. Préfabrication et combinatoires. ENSAPM, Paris, 2010

Figure 3.2.2 The Packaged House System. Built prototype. 1947

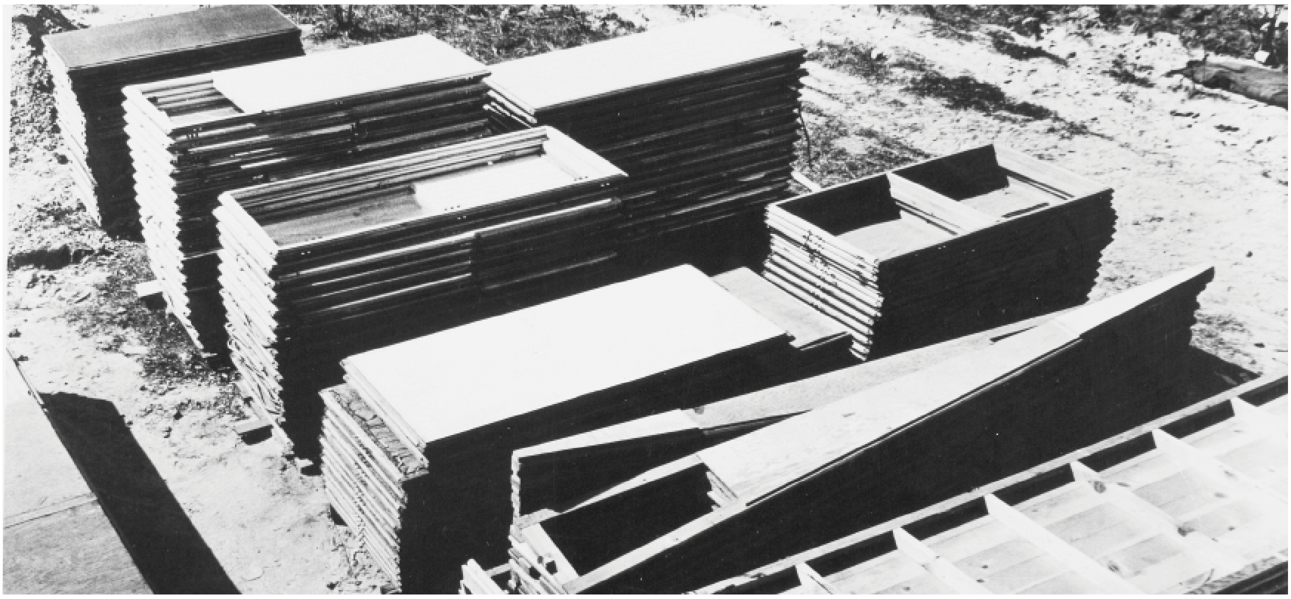


Figure 3.2.3 The Packaged House System. Set of panels and other components

3.2.3 OPENNESS. Systems can be qualified as *open* when they comply with a design condition that enables actions of addition and exchangeability, either of spatial units or building elements.

By its contrary, openness is about not to being fully enclosed. A *closed* system in its strict meaning is a definite set of elements in a relation without any input or output of energy, information or material to the environment surrounding the system – it's a system in isolation.[25]

From the point of view of the design, openness in a system refers to its condition of transformation, the capability of being flexible. The use of the term *flexibility* also have different connotations. In this case and accurately applied to modular systems, it refers to the capability of a design of being adaptable in its spatial composition and flexible in its uses and functions. For example, flexibility is expressed in its inherent freedom to relocate living spaces by moving internal partitions and include the possibility of plan growth.

Designed flexibility has been a subject of special interest for architects. The spatial indeterminacy has been sought since modernity in order to give architecture the possibility of changes in use and occupancy. Remarkable investigations were made in this field such as Le Corbusier's Dom-ino system (1914) which generated open plans that where structurally free and enabled for multiple interior arrangements, or Mies's close attention to the grid of the plan in his family houses or even more evident in the distribution of 860-880 Lake Shore Drive's building layout (1949).

Next there's the analyze of a blurry topic, repeatedly and carelessly shown in the related literature.

Besides the exploration made in open designs focused on the search for adaptability, mostly in terms of spatiality, the concept of openness is commonly also applied to the field of construction systems.

This point of view highlights the adaptability of a system to the material environment meaning its capability to incorporate a wide range of components offered in the market, without the limitation of integrating elements from a single source.

There is a big difference between both approaches; the open design point of view is related to a process in which openness is expressed in a more abstract way, where intentions of openness are reflected in the architectural design. The open construction system perspective is a totally product-oriented approach, and it's strictly about the manufacture of each component and the compatibility between industrial elements where physical obstacles must be crossed.

Modular systems manage to embrace both approaches simultaneously and many great examples had proved so. However, the debate isn't interesting enough without fully understanding that any of each point of view that one comes with the other.

Modularity as a condition of architectural design, tends to provide openness, speaking in terms of flexibility or adaptability of its space. The higher is the degree of modular design, the higher is the level of design openness and space adaptability.

Modularity as a condition of a building system -conceived as set of building elements with specific arrangement rules- may condition its openness, measured on the degree of refinement of the components. The highest level of prefabrication of its modular components is achieved, the lower degree of openness is given.

25 SÁNCHEZ VIBÆ, Kasper, Architectural System Structures: Integrating Design Complexity in Industrialised Construction, Routledge, UK, June 2014, pg 75

"The invention aims to transfer most of the labor involved in the construction of a building from the site of the building itself to a factory and to make the erection of the building primarily one of assembly". In order to achieve this "standard units or sections, each consisting fundamentally of a duplicate of the other" are used so that "any frame section can be interchanged with any other". In this sense the system was conceived as universal, with an infinite potential for combination of a set of standard panels, related to each other in three directions.

Description made in the patent application of The Packaged House.
Excerpt from HERBERT Gilbert, The Dream of the Factory-made House,

The Packaged House (1941-1952) represents an exceptional and totally adequate case study to expand on the theory of systems applied to architectural design.

Walter Gropius represents one of the leading heads in the development of industrialized, standardized and flexible systems. With a great variety of projects, he provided great advances in the conceptual framework of "unity and variety, flexibility and growth, stability and change, standardization and individual choice." [26]

At that time flexibility was one of the main concerns of the architects involved in prefabricated systems' designs. Flexibility meant: mobility, or the ease of transportation and adaptation to various locations and climes; adaptability, or capacity to generate many houses types and variations, through the interplay of standardized components; and growth, or the expandability of the house, horizontally through the addition of further rooms, or vertically though the addition of another floor.[27]

The search was for the manufacture of prefabricated systems made from specially design standardized components, under modular design guides with an open oriented plan to be adaptable and extensible, that could allow as many variations and uses as wanted.

The efforts were put into achieving standardization without sacrificing the individual needs of the owners. Industrialization would actually help to reduce the costs of manufacturing but not the quality of the domestic life. Great amounts of energy were put in the design of every building component in order to create a whole that would represent the qualities of open design systems, manufactured to be a closed system in its material conception.

26 HERBERT Gilbert, The Dream of the Factory-made House, The Massachusetts Institute of Technology, US, 1984, pg 259
27 HERBERT Gilbert, The Dream of the Factory-made House, The Massachusetts Institute of Technology, US, 1984, pg 138

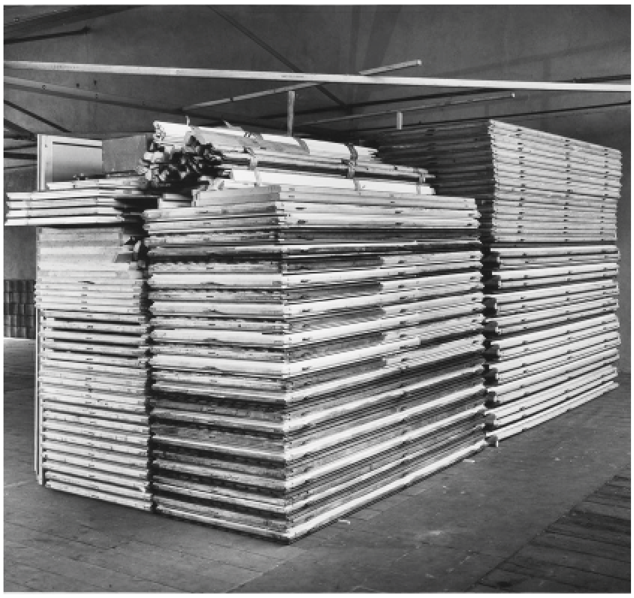


Figure 3.2.4 The Packaged House System. Set of elements storage on factory ready to be transported

3.2.4 THE PACKAGED HOUSE. The *'Packaged House System'* is an amazing example of a prefabricated panel construction system designed in 1941 by Konrad Wachsmann and Walter Gropius, both German architects who immigrate to the United States during World War II. This experiment is well known for its advanced conceptual richness and its theoretical intent to consecrate as a perfect and universal system. Less known is the commercial failure of the General Panel Corporation, caused by multiple unsuccessful commission agreements and the shortcomings of haven't achieved lower production costs.

Prefabricated and quickly assembly building systems were necessary during the World War II, for house the troops and give quick response and strategic auxiliary equipment. Also, it urged to meet the housing needs of the large number of workers settling near the factories producing equipment, armament and aircrafts. There was also a plan of action to be executed after the eventual end of the war years in which factories would be retooled to produce low-cost prefabricated housing for veterans and their families.

The project seems to have offered Wachsmann his most exciting design opportunity since his important explorations in prefabrication back in Germany, after the dark days of the WWII. He had already produced some drawings years before and he spent his first weeks in the U.S converting the drawings to the American unit system in the hopes of making the project commercially viable. He spent many years developing the project and its fabrication phases in order to improve it; he was particularly looking to achieve the universality of the system, redesigning its pieces again and again to prevent the mundane misfortunes of the manufacturing process.

The intention was to develop a house system that remains simple and architecturally modest. The entire house was conceived as a single repetitive unit, which could be assembled on site by basically trained workers. Timber was at that time the most economic building material available that assure a good quality-quantity relation.

The system has no ideal arrangement; infinite configurations could be made using the 3'-4" module grid and combining the 10 different types of the 10x120" wooden insulated panels, having the capability to adapt to various climatic and site conditions, the preferences of the owner and the taste of the architect. All the building surfaces, horizontal or vertical, were built by the same panels: exterior walls, roof, ceilings and interior partitions.

What's most remarkable of this system is that it remained under an abstract but very precise design. The great achievement was its original x-shaped wedge connectors and the metal *'universal joint'* housed in the edge of each panel. It was based on 2, 3 and 4-way connections between panels in any direction.

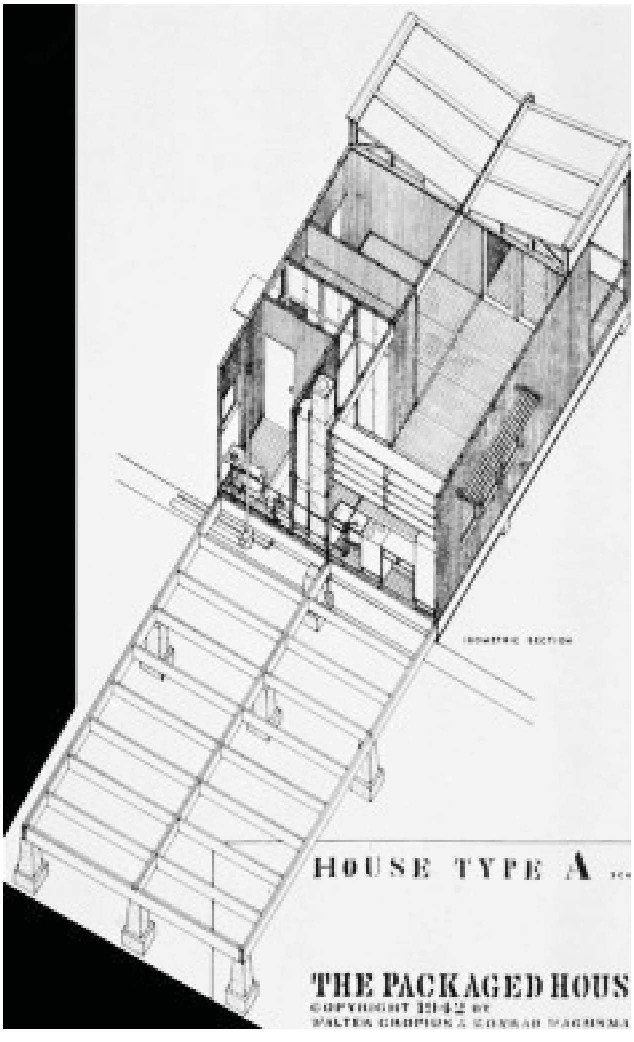
To fully control the production, the assembly lines were specially invented in order to perform the different manufacturing stages: sizing of the wooden boards profiles, cutting of slots on the panel edges, insertion of the assemblage metal hook into them, gluing the structure with the cut panels, double gluing of the plywood, treatment with weather resistant resin (different depending on the use of the panel in the horizontal or vertical direction), and finally, the storage in the correct position ready for transportation by truck to the final on-site assembly.[28]

28.SCHWARTZ T., Sadettan S., Seron P. Préfabrication et combinatoires. ENSAPM, Paris, 2010

These studies (of Gropius) in prefabrication demonstrate a theme, a clearly defined pattern. The emerging theme embraces a trilogy. It is the simultaneous satisfaction of the technical function: “to accept the challenge of the machine in all fields of production”; the aesthetic function: “the prefabrication of houses on a unified artistic basis”; and the human function: ”the satisfaction of the public desire for a home with an individual appearance.” The theme is the unification of technology, art and life, the fundamental unity upon which the entire structure of Gropius’ concepts and works is based.

HERBERT, Gilbert, The Synthetic Vision of Walter Gropius, 1959

Figure 3.2.5 The Packaged House System. House type A isometric drawing. 1942



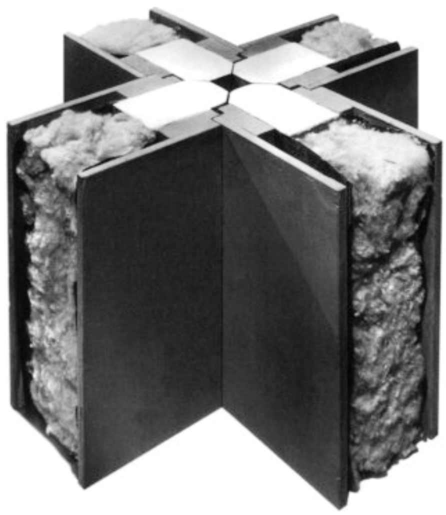


Figure 3.2.6 The Packaged House System. Panel wedge connections mock-up

The Packaged House rapidly appears as a closed system if attention is placed on the design and coordination of its elements, while it can be actually understood as an *open system* considering its primary goal, that was to remain undetermined in its final forms, be adaptable and changeable. The system reveals a particular duality: while it's indeed a *closed system* in the restricted use of components, is at the same time an extraordinary example of an *open system* that allows endless configurations and ways of enclose the space with no preconception of a room unit design.

It was a rational system in that the number of components was severely limited; but for all that, it was closed.[29] It wasn't based on the industrially produced building components available at that time. It didn't also adjust to the standard industrial norms, so it became incompatible with introducing other elements.

From the point of view of the design it was an ope-ended system that allowed the maximum flexibility of the floor plan distribution. The limits were set by the parameters of the construction system that determined the designs were "all rectilinear, modular, panelized, and low-rise."[30]

What's different and new in this building system is that it introduces the elements as complete entities that create directly the enclosure for the inner spaces, not depending on a primary frame structure. The panels specially manufactured and easily assembled, constitute in a single step the body of the construction.

Other systems developed in the same time offered multiple-layer solutions that depended on the first structural grid in order to receive the cladding components. The Packaged House offered an integrated solution as its elements were brought together packed in a truck and locked on site in any direction. Although the universality of the joining system, it wasn't actually a do-it-your-self model, trained workers had to assemble the elements under strict quality controls.

It was hoped to be market just the set of limited universal components that derived in unlimited alternatives of designs. Due to the American building regulations and financial requirements for approval, the dream of universality was to be abandoned into more conventional ways. The company had to produce a limited range of standard houses that translated the system into specific typologies of buildings.

Despite of the enthusiasm for the project, the commissions and founding received the benefits of the short construction time required and the two well-known architects in charge, The General Panel Corporation closed its doors in 1952 before the big dream came true. The project failed in the production timing -design requirements and adjustments took too long- and its costs not ever succeeding in the American housing market.

Technically, the Packaged House was a very refined first-class product. The causes of the failure were not, in any substantial degree in the architectural conception, nor in the technological means, nor in the translation by industry of that conception into the reality of building components.[31]

Many were the factors that made this dream fade off, a combination of many external factors and the excess of time and money it took the preliminary stages of design to be transformed into an actual industrial product, weakening the primary idea of all those years of true and hard work.

29, 30 HERBERT Gilbert, The Dream of the Factory-made House, The Massachusetts Institute of Technology, US, 1984, pg 255-256
31 HERBERT Gilbert, The Dream of the Factory-made House, The Massachusetts Institute of Technology, US, 1984, pg 307

“Genuine variety without monotony could have been attained if we had taken greater interest and influence in the development and design of an ever more comprehensive production of standardized, component building parts which could be assembles into a wide diversity of house types. Instead the idea of prefabrication was seized by manufacturing firms who came up with the stifling project of mass producing whole house types instead of component parts only. The resulting monotony further deepened the horror of a nostalgic, sentimental, unguided public of prefabricated future.”

GROPIUS, Walter, Apollo in the Democracy: The cultural Obligation of the Architect.
Excerpt from HERBERT Gilbert, The Dream of the Factory-made House

Figure 3.2.7 Walter Gropius and Konrad Wachsmann in the construction site. 1947

Figure 3.2.8
A. The Packaged House System. Finishings catalog
B. Standard house type. Exterior appearance
C. Constructive three-dimensional section
D. Modular floor-plan design based on a orthogonal grid

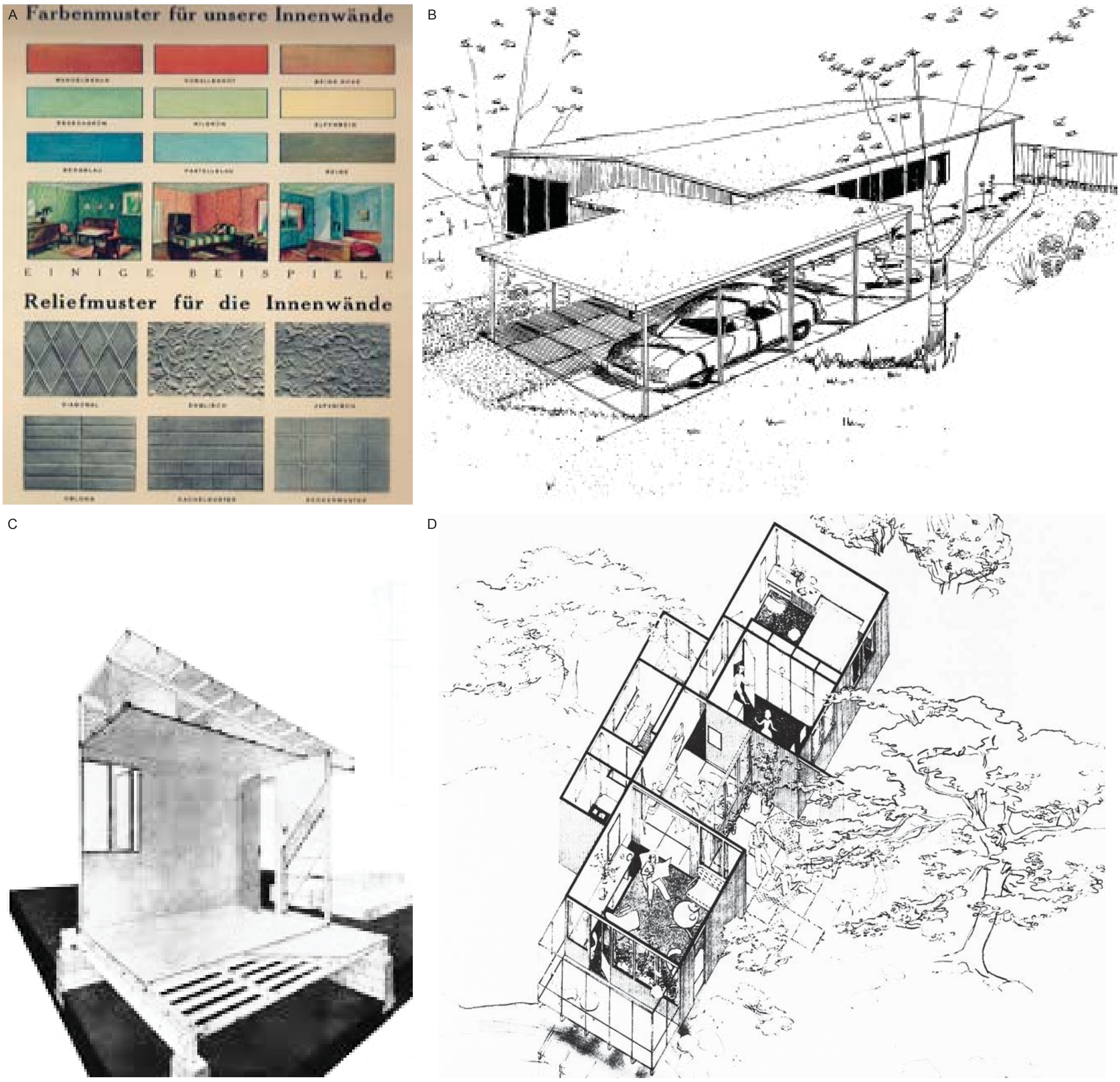
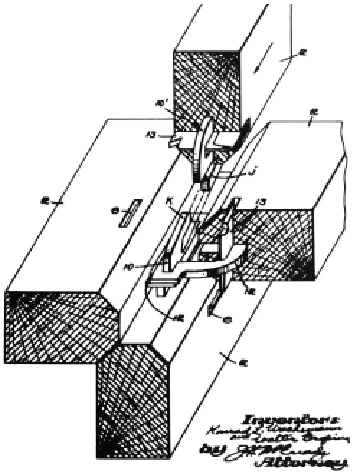


Figure 3.2.9 The Packaged House System. Built prototype. 1947

Figure 3.2.10
A. Multi-position metal hook
B. Four panel hook connection
C. Two panel connection, wedge wooden profile
D. Panel types hook position

A

B



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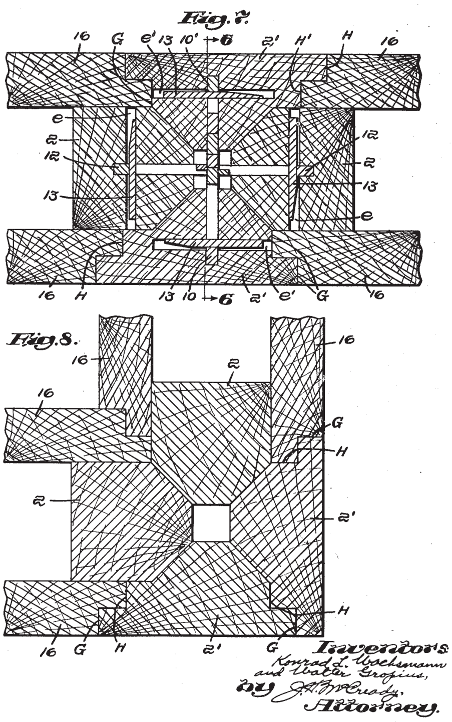

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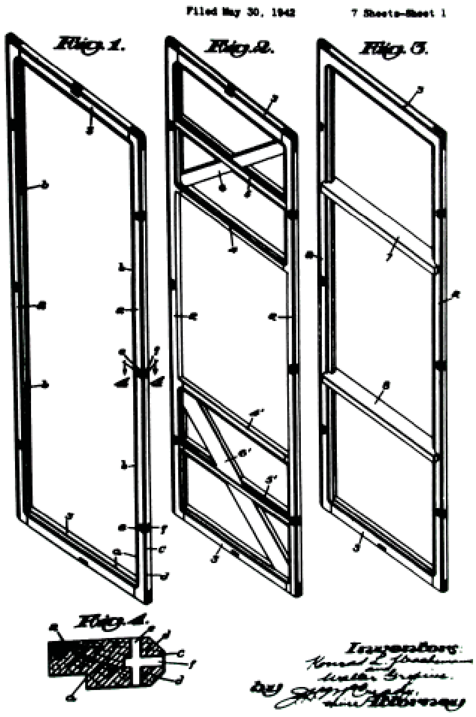
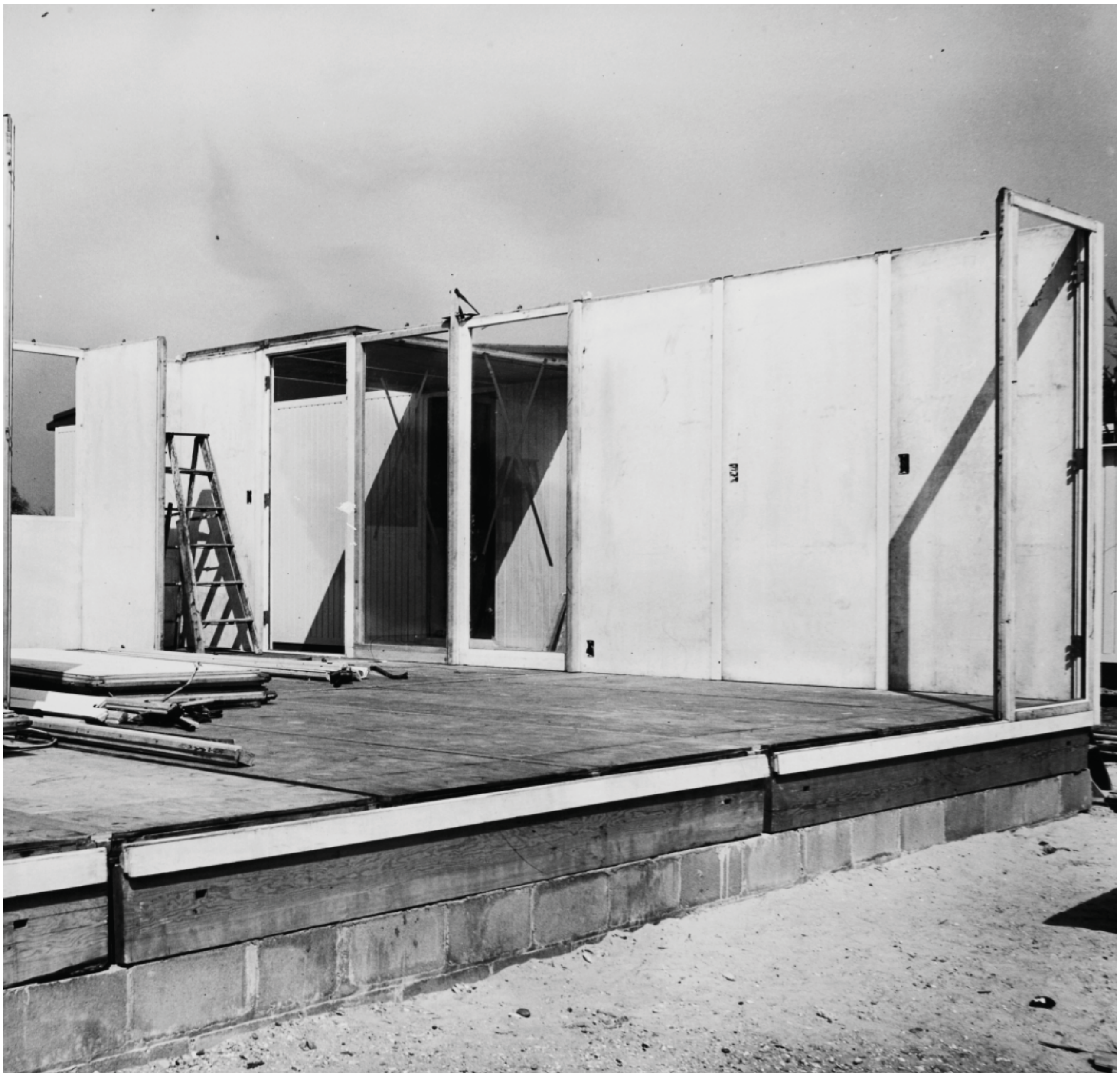


Figure 3.2.11 The Packaged House System. Built prototype. 1947



3.3. ADDITIVE PRINCIPLE

Modular systems' potential to change.
Searching for indeterminacy: Espansiva System

3.3.1 CUSTOMIZATION. Since the beginnings of the 20th century, the industry looked for cost efficiency and economic sustainability of construction systems and many architects have leaned towards avant-garde designs conceived to be adaptable to use, climate, location and time. The search for serialization of building components to be part of customizable architectural products lasted for several decades and still prevails in the architects' agenda. Although the great majority of these systems had proved to have its own constrains -most of them were rapidly discontinued and so its adaptability faced important limitations-, significant advances were made in both design and building fields.

The possibility of customization of a dwelling has been reformulated again and again along history. Besides construction methods haven't always been fully responsive for complying with individual client requests, industry have demonstrated –mostly the automotive and aeronautical- that customization is a real possibility and technology is already available for manufacturing both standardized and customized elements, not necessarily increasing production costs.

Digital production and advanced design methods have open the doors for architects to deal with industrial construction challenges. Building processes have evolved enough to achieve new goals being optimization and innovation in production the order of the day. Future progress in industrialized construction should enable the quality improvement of architectural products while promoting cost reduction. The economy of scale seems to be the crux of the matter, understanding that real adaptability of dwellings is conditioned by the associated costs; to succeed, customization must be affordable.

Parametric design and computer controlled machines have made customization a standard procedure in furniture and clothing industries; this trend is known as *mass customization*.[32] As a paradigm emerged not more than a few decades before representing the notion of customized products and economy efficiency. For this to be possible, processes and also products are thought as systems, meaning that they are geared towards gaining openness and flexibility that will be directly translated to freedom in terms of design.

Modularity applied to architecture, both in design process and building systems' development, represents in this case, a tool that may help achieve this challenge. Not only is mandatory to gain flexibility in terms of space, it is also of paramount importance to make dwellings easily adaptable according to the natural changes during the inhabitant's lifetime.

Modularity is an essential part of any mass customization strategy. Each module serves one or more well-defined functions of the product and is available in several options that deliver a different performance level for the function.[33]

Not only customization has to be understood in terms of aesthetics -envelope exchangeability- but also in time, taking into account the natural changes of uses that claims for physical adaptation along the building lifetime. The value of being adaptable slips into each of the design stages, even conditioning since the very beginning the design and manufacture of each and every component.

The capability to change its inner and outer appearance, commit with the requirements of its function and being able to evolve over time represents the reason to be of architectural modular systems.

32 DETAIL Components and Systems: Modular Construction, Design Structure New Technologies, Birkhaüser, Munich, May 2008.
33 PILLER, Frank T., Piroozfar, Poorang A.E, Mass Customisation and Personalisation in Architecture and Construction, Routledge, UK, 2013. pg 20.

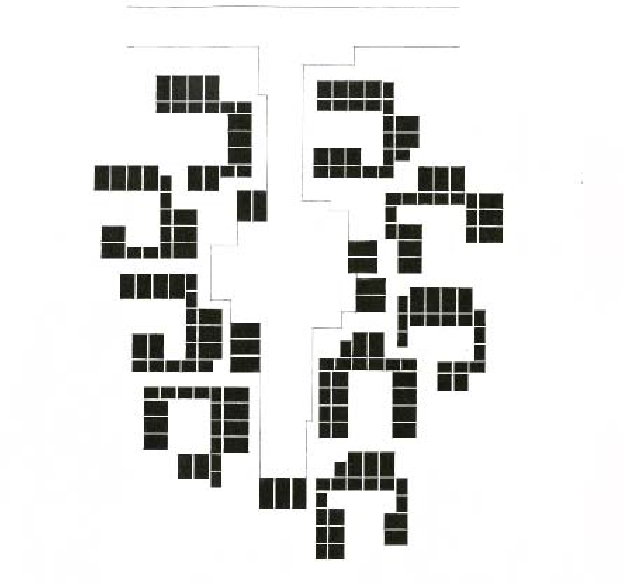


Figure 3.3.1 Espansiva System. Utzon's scheme for singular housing complex

3.3.2 ORGANICISM. Jørn Utzon's fascination with the growth of the natural forms and the vernacular architecture additive logics, made him develop ideas over the process of evolution. From his perspective, the nature was the best example of standardization.

He deeply admired the cohesion and architectural integrity of the desert villages of the Islamic architecture in Morocco, the organic architecture of Frank Lloyd Wright's buildings and the systematization developed in the Californian CSH program. Having also been influenced by his travels through China and Japan and after years of testing theories about the systematization of the building processes and the study of the history and demands of the family house, he came with the idea of conceiving a set of building elements capable to form diverse types and scales of buildings by simple permutation of the units.

Based on the knowledge that within nature infinite variety can be generated by a modest number of elements, Utzon worked on the idea of an '*Additive Architecture*' that provides a major theme and basis for his architectural design processes.

Utzon additive architecture is based on standardized modules that are linked together by pure addition without changing the basic module. He was able this way to achieve organic forms regardless the geometric character of the module units. Another advantage is the ease of adaptability this architecture shows when it comes to suit the program, as well as the ability to morph it in the future.

Utzon planned variants of this modular system that fluctuated in size between one-room huts to multiple bedroom single family houses and one prototype was built in a small plot as a patio-house model in Grammel Hellebaek north of Copenhagen in 1969.

This is how Jørn Utzon highlights the virtues of a modular-based architecture with a simple building system that hides complex genetics, while using the modular system not as a design constraint but as a source of inspiration.

In 1958, on his return from his visit to China he rethought his work and encouraged his drawing team to embrace this new approach to architecture: *as well as under lower temperatures, Chinese people put on several layers of the same clothing one over the other and they took some over when it gets warmer.* This example changed the way in which the office thought and created the bases for him to mature the principle applied to architectural design that stated that what could be added could also be removed again.

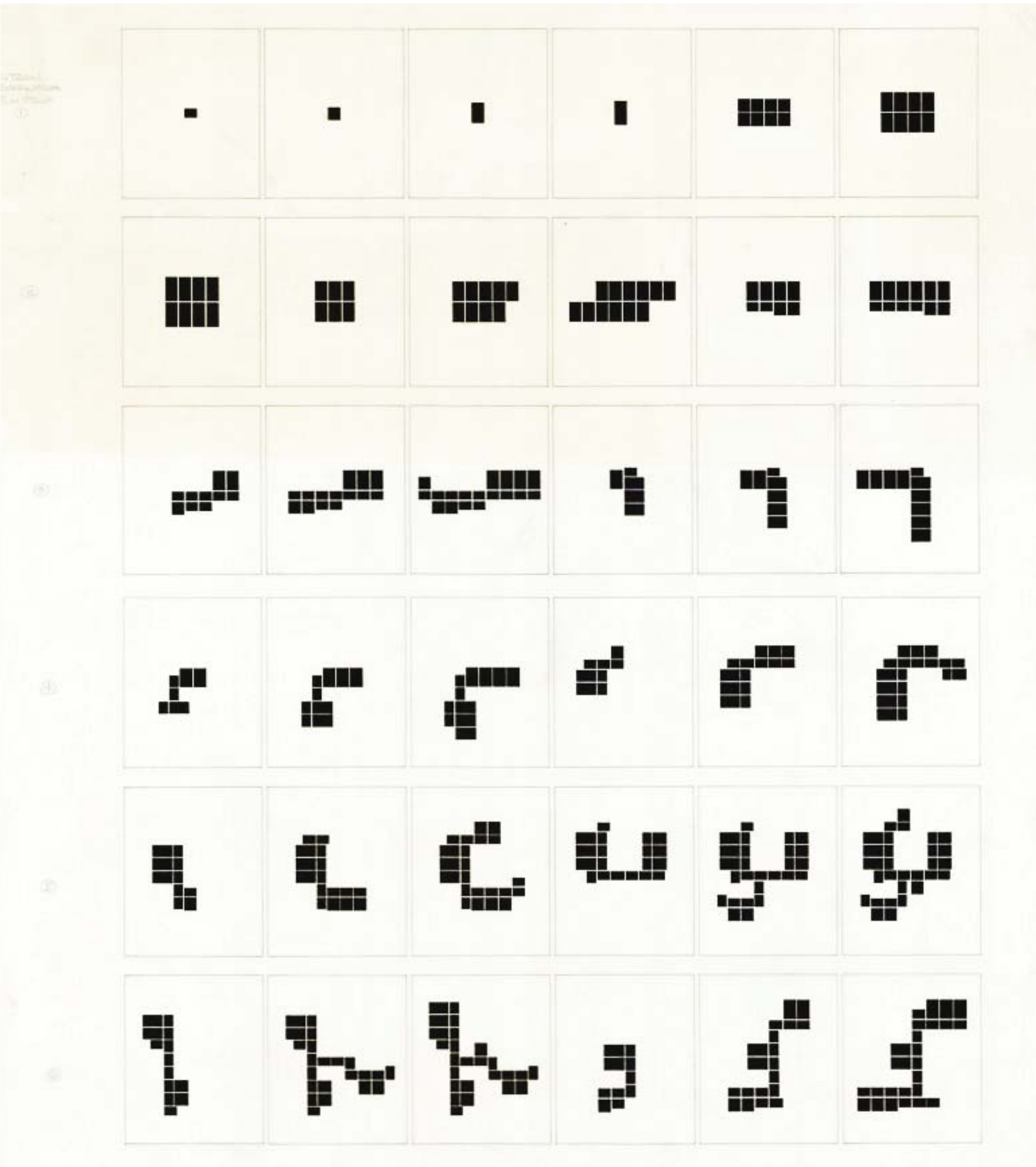
It was during the construction of the Sydney Opera House that this idea poured into what he called *Additive Architecture*.

Utzon –who along with Philip Johnson is the last surviving member of the heroic age of Modernism- used his intuition and ability to observe the world in such a way so he could avoid both the reductivism of a vision in awe of the machine and an eclecticism that views all value systems as equal in value.[34]

A question naturally arises and leave us wondering if it's actually possible to merge the design implications of standardization and homogeneity -identified as intrinsic features of rationalism- with the idealism that flexibility and adaptability in architectural design represents. The Espansiva building system, reflects the genuine understanding of the prefabricated construction unit as a vital factor for a flexible, variable and evolving architectural design. Staying simple and conceptual, the system manage to respond to the forces of change through rich spatial arrangements that the combination of different basic units allowed.

34 POPLE, Nicolas, Small Houses: Contemporary Residential Architecture, Jrence King Publishing, UK, 2003

Figure 3.3.2 Espansiva System. Utzon's diagram of possible arrangements with modular housing units



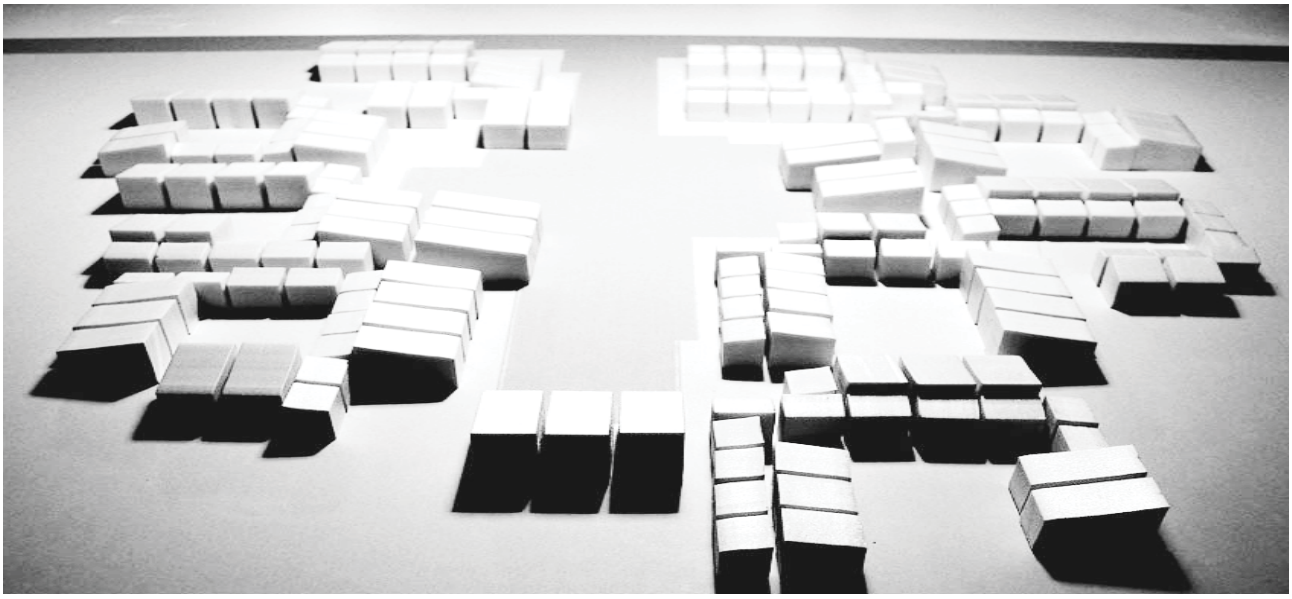


Figure 3.3.3 Espansiva model of a singular housing complex

3.3.3 ADDITIVE ARCHITECTURE. The so-called *Additive Principle* consist of a method based on the design of a basic living unit that reflects the functional nature of the program, the following formulation of a set of arrangements and its method of assembly according to the site conditions and construction schedule. Basically consist of a composition made by addition of modular units. From Jørn Utzon's point of view, it isn't only about adding structural elements that share common standards to one another. Building components are to be considered autonomous and equally significant in the whole, not only in theory but also during the construction process.

In his 'Additive Architecture' manifesto written in 1970[35], he explains his own particular vision about the value of each component and the relation to the whole, saying that despite of being part of a pure addition principle that becomes a new form, every individual component manages to find its architectural expression.

Also, he was devoted to the systematization of the building construction process. He states: "A consistent utilization of industrially produced building components can only be achieved if these components can be added to the buildings without having to be cut to measure or adapted in any way." [36]

Implicit within this additive principle is the process of industrialization of the components, the repetitive mass production and the act of prototyping in three dimensions that helps greatly to solve design issues and enhances the improvement and adjustments needed.

The Espansiva building system conceived by Utzon in 1969, constitute one of the most visionary statements of the history of prefabricated architectural design. The sum of the idea of standardization and the principle of addition gathered together in a rational modular design, supported by his own theories, exceeded the limits of the discipline. He simply based these ideas on the observation and understanding of the nature logics and structures, growth and development.

Utzon also have had his own approach to the systems' theory. Espansiva was conceived as an open system, that would contain adaptation potentials to respond to the requirements of the client, the site, the program and also the market. In contrast, he argues that a close system is based on a number of components which, when they are repeated, make up a singular but predictable architectural design.

His own definition of the *Repetitive Principle* is based on the fact that construction elements are closely related by its form and repeated in accordance with a logical system and aesthetic intention. In contrast, the *Additive Principle* is, from his perspective, a matter of defining a variety of construction elements added to one another in many ways, offering a whole range of architectural solutions. The construction elements are designed from a more pragmatic point of view, seeking to obtain a high degree of flexibility. Each piece assists the whole design offering different functions and variations that allow multiple combinations.

In order to distinguish even further between the two systems, one may conclude that the additive building system can contain repetitious elements, whereas the repetitive building system deals only with components that are part of a designed system.[37]

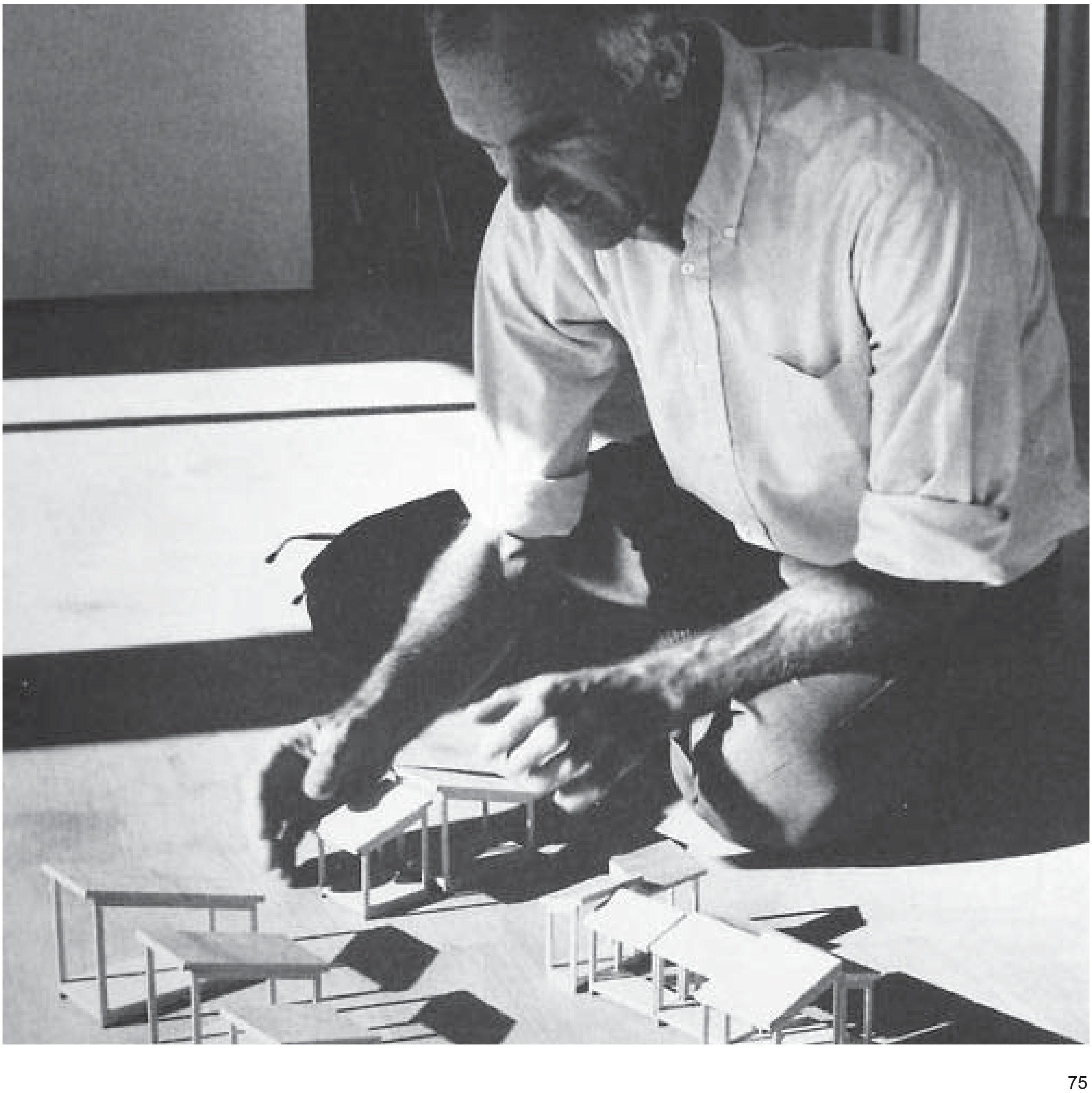
Openness, in this case, is valued for the capability of the system to be undetermined, to set free the architectural product final form and favor the possibility of real mutations by simply adding basic living units.

35, 36 UTZON, Jorn, Additive Architecture, Arkitekture DK, no.1, 1970
37 BEIM, Anne, Tectonic Visions in Architecture, Kunstakademiets Arkitektskoles Forlag, Copenhagen, 2004, pg 119-138

“My ideal of industrial prefabrication in house building is a building system similar to the log-house system, in which neutral, uniform, identical components can give shape to a variety of buildings.”

Utzon, Jorn, Interview with Markku Komonen, Arkkitehtii, 2/83, pg. 46.

Figure 3.3.4 Jorn Utzon working with modular basic unit models



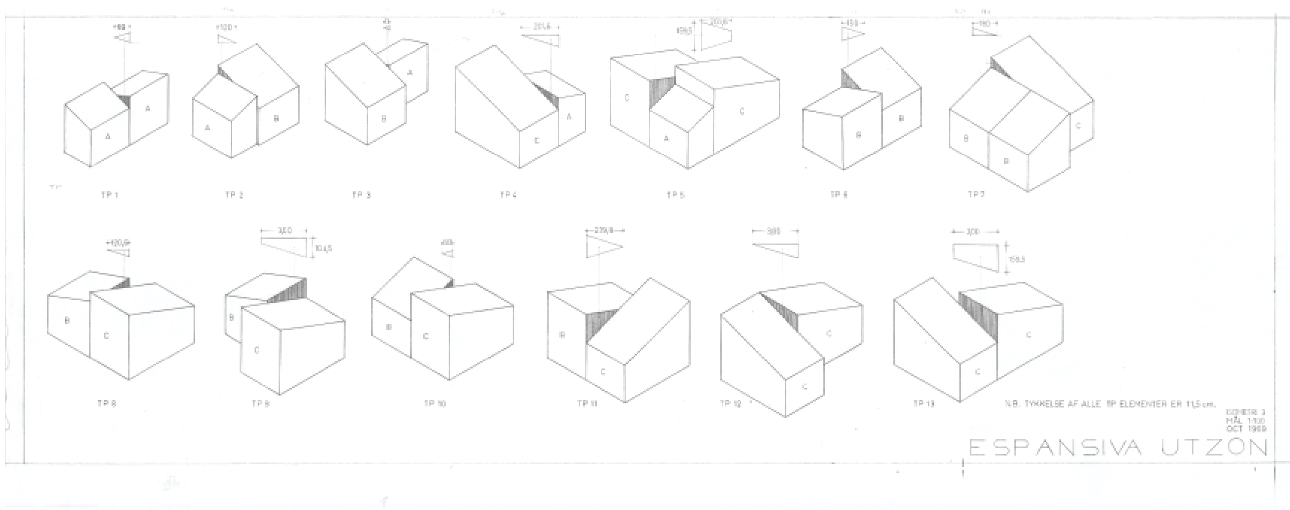


Figure 3.3.5 Espansiva System. Basic unit combinations. 1969

3.3.4 ESPANSIVA. The Espansiva system was designed in the 60s as a reflection of Utzon's principle of *Additive Architecture* and conceived as a modular open system to be as flexible as possible and totally responsive to users' requirements.

Its architectural expression reflected the principles of functionalism that represented an essential feature of true architecture. The compliance with this basic principle would only enhance the advantages of modular construction, providing greater control over the production, a significant reduction in costs and a much faster and efficient execution in contrast to the traditional craft architecture processes.

Utzon refers to the organic conception of the system with these words: "If one passes on to nature, one will see that the elements of nature are created out of a multitude of small identical elements of very different nature and characteristics, which multiplied or combined with other sorts creating an infinite richness and grandeur in terms of space, matter, form and color".[38]

Utzon cites himself this words when expressing his ideal over modularity in additive architecture: "The tenet of functionalism, which is after all the essential background to true architecture, is respected. The drawings are not a thing per se with meaningless and dimensionless module lines, but the module lines represent wall thicknesses, and the lines on the paper form the contours of the finished thing. The projects show the degree of freedom that can be achieved with the additive principle in tackling greatly varying tasks."[39]

Espansiva was a catalog house composed by modules of small functional units of three different sizes -same width and variable length- designed to be placed side by side without partitions to create larger inner spaces. Each unit was defined by its function: corridors, bathrooms, bedrooms, kitchens and sitting rooms, meant to be attached to each other by the requirements of use, structure and construction principles, creating a bigger pavilion under one tilted roof. The number of unit versions here is very limited and so are the rules that determine the linking methods.

Although it seemed like a very simple table game, the amount of permitted combinations of units to form a great variety of floor plans arrangements *–I, U, L shaped-*, seasoned with the possibility of combining open courtyards, gave the system an unimagined complexity.

The units were designed as mono sloped simple rooms, with four timber corner posts and non-bearing insulated walls with a regular span between the posts that determined the size of the length of the units. The structure is integrated and centered on the partition wall elements that continue to the roof, leaving a twelve cm separation between them, as a fire-proof gable. This interstitial space was perceived as a construction element itself. The measure on twelve cm derived from the Danish brick and depending on the general design of the house floor plan, that 'leftover space' could be filled out or left open. This way, the wall thickness can be perceived as part of the module system, reinforcing the fact that it is made of independent components, each being a unit itself.[40]

The same richness variations given to the floor plan design was proposed for the cladding materials. For the external appearance of the house, a great variety of cladding panels were considered adequate and feasible to be combined.

38 UTZON, Jorn and Tobias Faber, "Tendenser I Nutidens Arkitekture", pg 66
39 UTZON, Jorn, Additive Architecture, Arkitekture DK, no.1, 1970
40 BEIM, Anne, Tectonic Visions in Architecture, Kunstakademiets Arkitektskoles Forlag, Copenhagen, 2004, pg 119-138

"Again, when working with the additive principle, one is able to avoid sinning against the right of existence of the individual components. They all manage to find their expression."

UTZON, Jorn, Additive Architecture, Arkitekture DK, no.1, 1970

Figure 3.3.5 Interior of a Espansiva housing prototype built in Grammel Hellebaek, Copenhagen. 1969

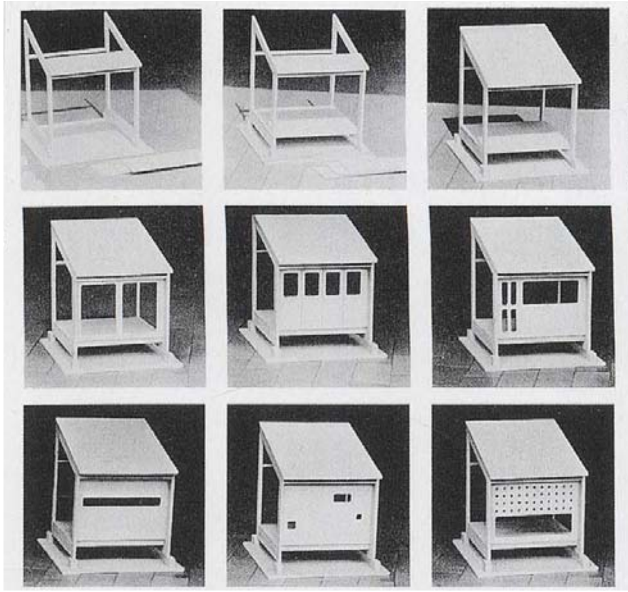


Figure 3.3.6 UTZON, Jorn, Additive Architecture, Arkitekture DK, no.1, 1970

A thorough analysis about the actual needs of a regular single family dwelling, led to the conclusion that a framed structure by beams and column best fit the growth requirements. The frame condition establishes a reduced number of fixed points while the external and internal walls between them are left absolutely removable. The space between structural base points set the basic module unit that correspond to different room functions, being free for accommodate the modules according to personal choice.

The small pavilions corresponding to each unit were design to be independent self supported room-sized volumes. These units could be found in 3 different depth measurements: *Module A* 213,6 - *Module B* 333,6 - *Module C* 513,6 cm, respecting the only width possible of 300 cm. The single 17 degree one-slope roof increases regularly together with the modules' length, providing a rich variation of room heights.

Each unit is supported by foundations made of concrete beams leaning over on-site poured concrete cylindrical pipes. The floor is slightly raised above the ground and constituted by lightweight concrete elements, that itself provide the necessary insulation The laminated wooden columns are linked by means of rafter, forming a frame that is bolted together on the building site with a triangle as a standard brace. The sloped roof allowed freedom of choice between many kinds of roofing. The supporting roof surface consist of insulated roof elements extending from frame spar to frame spar.

Walls and partitions are made in the form of a wooden skeleton construction clad with waterproof plywood on either side, the space between being filled with mineral wool insulation. The wall elements are fixed to the posts by means of French screws, and the operation can be carried out with a spanner. All the elements can be dismantled again using the same tools if it should be desired to make alterations or additions.[41]

Different module designs have their own potential for use. The catalog made for the Espansiva-BYG System explains not only the physiognomy of each component of the systems but also the different modular arrangements and units purposes.

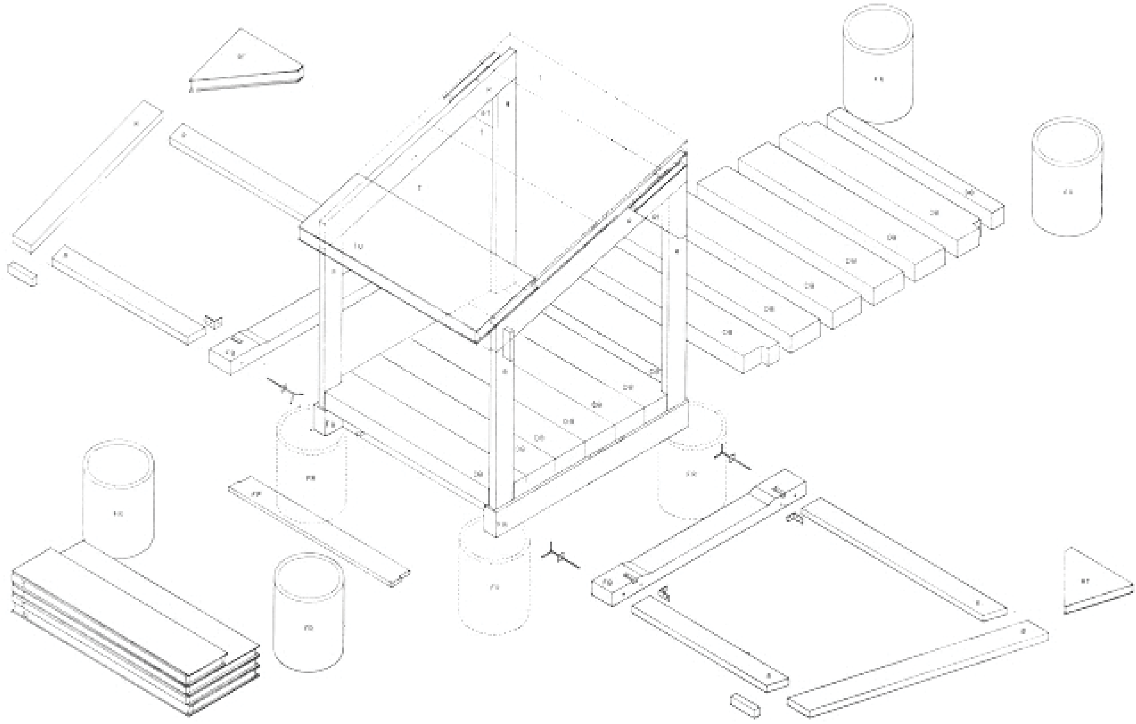
For example, the smallest one, Module A, measuring 3x2.13m, can be used as covered corridors, waking closets, complete bathrooms and toilets. The dimensions 3x3.33m of the Module B open up the possibility of being employed as sitting rooms, single bedrooms, kitchens, covered terraces and saunas, among others. Module C, measuring 3x5.13m give the possibility of installing a complete kitchen, a dinning room, living room, double bedroom, studio, etc.

The catalog emphasizes the capability of the system to be adaptable to uses and flexible in future arrangements offering all potential functions that best fit at any stage of the family conformation. The functionality of the home was supposed to be accomplished by the simple combination of various modules offering the chance to being further improved.

Simple or asymmetrical combinations of different module sizes would allow achieving exciting spatial effects, giving multiple arrangement options not only in the floor plan but also in the ceiling game of heights. The external appearance of the house was equally customizable by the wide range of cladding panels available that suit the system. Many combinations of opening and closing elements were offered to meet the needs of every space and will of the owner.

41 UTZON, Jorn, Logbook Vol. V.. Additive Architecture, Mogens Prip-Buss & Edition Blondal, Germany, 2009, pg 132-133

Figure 3.3.7
A. Espansiva basic modular unit: Structural set of components for assembly on site.



B. Espansiva basic modular unit: Envelope set of components for assembly on site.

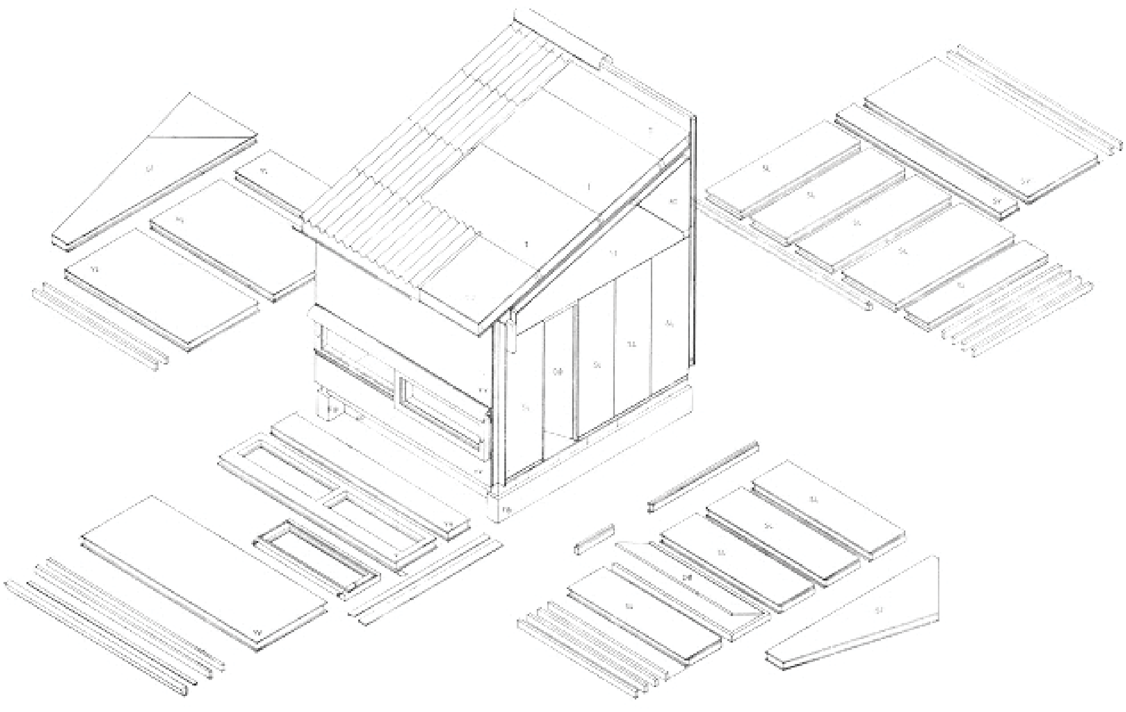
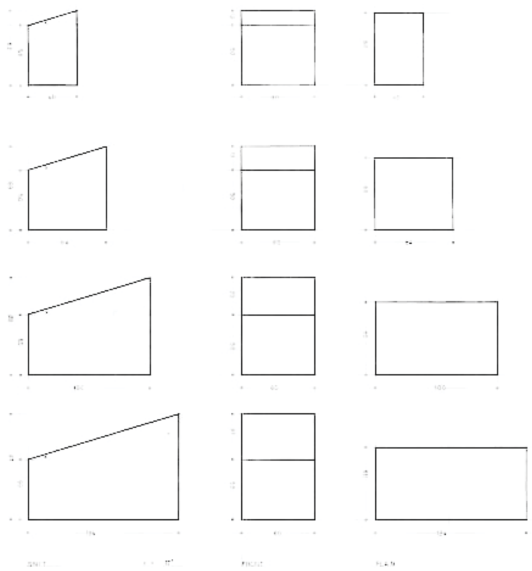


Figure 3.3.8
A. Espansiva units plans. Different module lengths and heights
B. Minimum unit structure of wooden columns and beams
C. Facades of one composed singular family house

A



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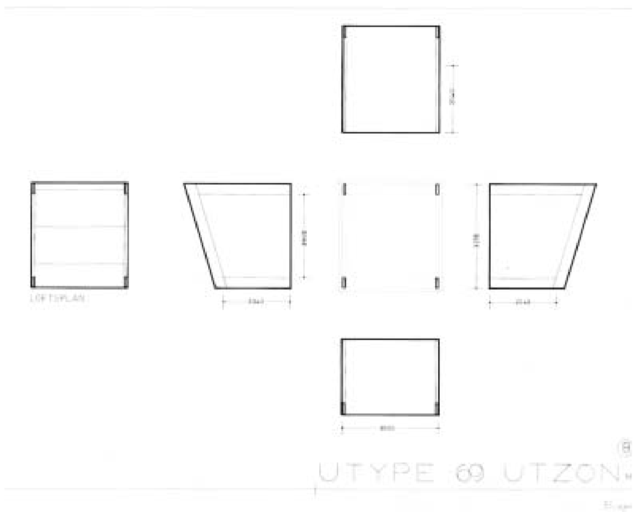

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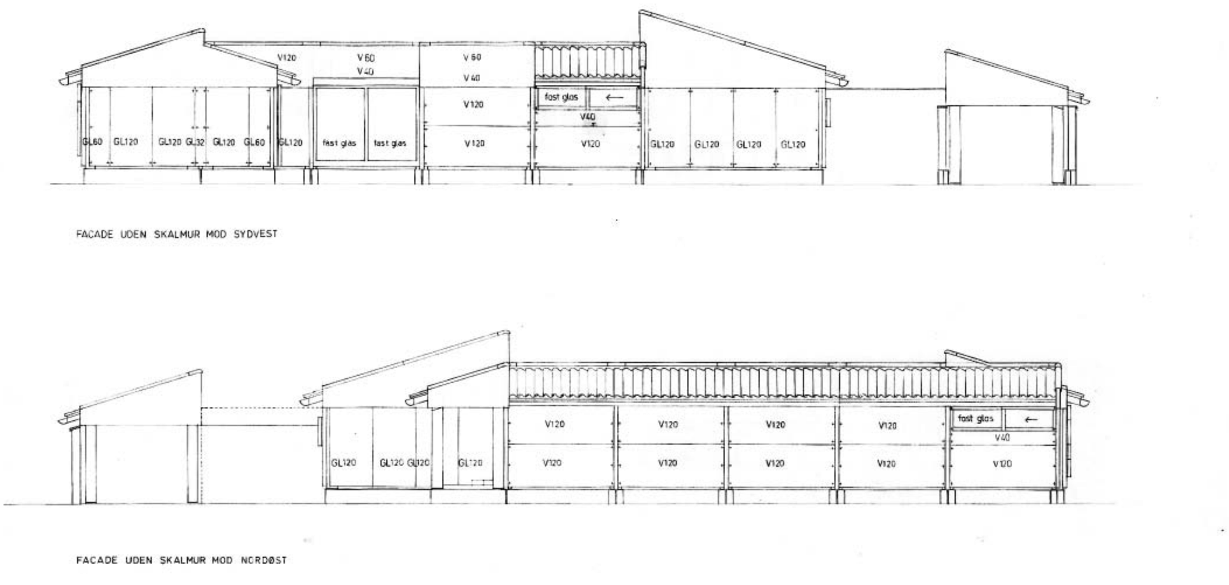
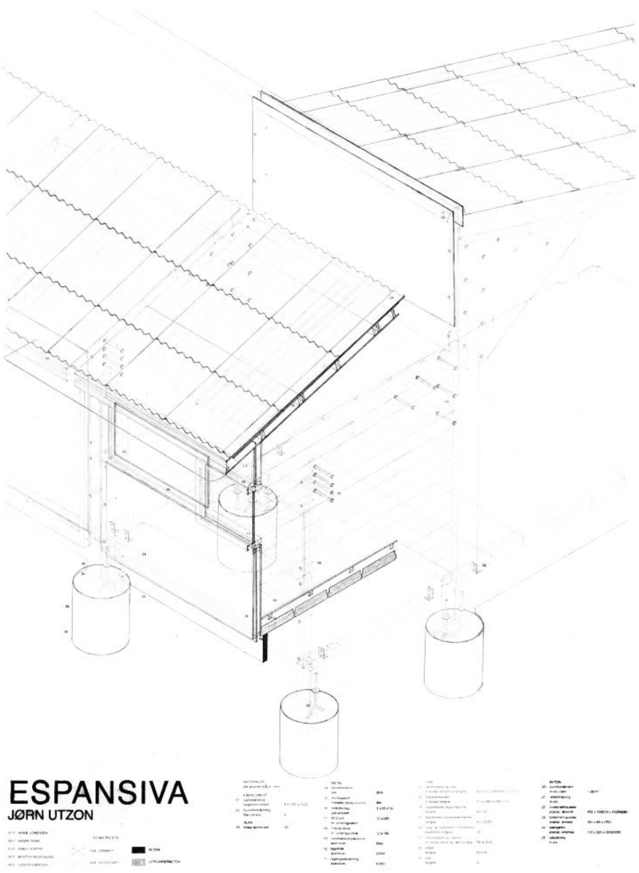


Figure 3.3.9
A. Courtyard interior facade. Volumes' height variation
B. Street facade. Volumes' articulation under a unifying one-sloped roof

Figure 3.3.10
A. Isometric three-dimensional drawing
B. Constructive vertical section
C. Assembly on-site sequence

A



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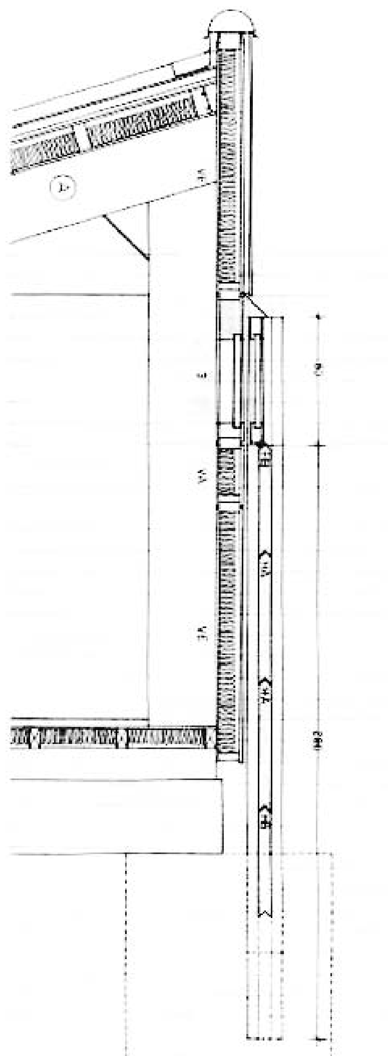

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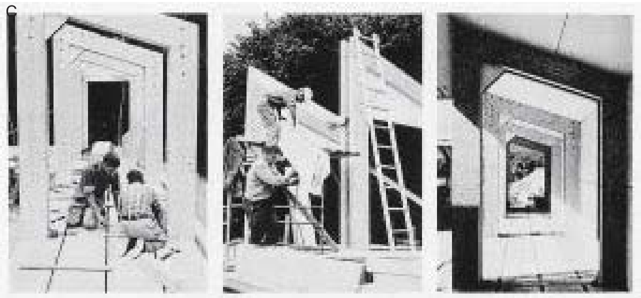


Figure 3.3.11 Japanese-inspired configuration with a prominent opening towards an inner courtyard

4. OVERVIEW

4.1 CROSSED ANALYSIS. As well as teaching us many lessons in the field of design, the systems reviewed also left us a high quality of knowledge on technical solutions that still today remains as a sample of unquestionable references of architecture, design, and construction industry. They were the result of a time of an intellectual boiling state, were architects were not only concerned about reassessing the past architectural vanguards but also about looking for improved design solutions to meet the actual dwelling demands of the countries experimenting a recovery during the postwar period.

The three of them represent excellent trials that approached successfully -in their own ways-, the concept of modularity in architectural design. They also constitute outstanding instances of improving the prefabrication techniques in order to meet the requirements of its advanced designs. These modular systems took a turn, offering industrialized solutions and far surpassing their contemporaries in their designing quality and tectonics.

Despite being all conceived as lightweight systems of standardized parts to be assembled on site, they handle different design concepts behind.

There's a major difference between prefabricated systems and modular systems, and it relies on the fact that the design process exceeds the merely constructive issues to acquire more complex attributes. All of them are the result of the search for the systematization of processes both design and construction, the relentless hunt to find solutions that are adaptable to use and the time changes, and always looking to fit the surrounding environment.

They all show a great effort to stay as simple as possible and not leave behind the promise of infinite possible combinations of parts that allow adaptability according to user's preferences.

These systems analyzed all together, managed to explain the key concepts behind modular designs and despite being the result of personal investigations of the architects, they provide great general conceptual contributions.

Having delved into their design processes, a common factor may be highlighted: each design is based on a modular grid that sets the pace and defines the spatial framework while the corresponding tectonics explores different geometrical -spatial and structural- solutions (frame, planar, volume).

Their own approach to modularity is reflected in the way the architects conceived the system as a whole. While the Moduli 225 responds to an orthogonal grid to which space is defined and frame structural elements are disposed of, The Packaged House is conceived as a system of planar structural pieces that are interconnected elegantly through sophisticated joints, allowing a great variety of spatial configurations. Meanwhile, Expansive is designed to be a sum of variable volume living units assembled on site, that have sufficient independence to be autonomous and its combination results in a modulated by irregular spatial distribution.

As seen before, Gullichsen and Pallasmaa found their inspiration for the Moduli 225 design in the studies of the great masters of the modern movement and continued the search for a universal language that gave life to an absolute anonymous and refined domestic architecture. The simplicity of the system relies on the resultant minimum number of pieces and the great variety of combinations allowed.

Figure 4.1 Moshie Safdie working on his Habitat 67 model. Montreal, 1967

The orthogonal grid, cubic mesh, and frame structure release the composition to infinity.

The flat roof constitutes a major advantage that allows connections by its four faces, not needing almost extra arrangements to grow or adapt the building. As any assembly-on-site building, a certain amount of handwork is needed for fixing joints and roof sealing. The scale of the modular grid and the minimum section of the structural wooden pieces makes this system be used only for housing requirements.

This example stands out for its great mastery of the framed modular space, the great exercise of volumetric total abstraction, the successful achievement of a universal language and the maximum of prefabrication gained.

Gropius and Wachsmann let their academic background and industrial previous experience to guide them towards a practical system of high-quality standards, based on neutral aesthetics and great adaptability to any kind of function. The Packaged House represents a system capable of adapting to any proposed function on the base of prefabricated panels versatile enough to build any desired program. The strength of the system is in the physiognomy of its constitutive panelized elements, simultaneously closing and structural, that can be easily assembled in any position and direction defining themselves the modular master grid. The lack of the system relies on its sloped on-site roofing solution that certainly limit the possibility of future arrangements, either growth or reduction of inner space.

The system design by Utzon is based on his particular fascination for the natural growth and adaptability of organisms that is directly reflected in the design of the basic units that were given a more traditional look but filled with great potential for addition and customization. Espansiva has a reduced variety of units' sizes with total independence given to each one that leads to more complex and organic floor plans, fulfilling the real demand for space required by its users. Flexibility is actually achieved by the ease of assembly of autonomous programmatic units. Modularity, in this case, is represented by the conception of each unit as a module despite being assembled on site and although its independence makes the system double the structural elements.

The major weakness is found in the great amount of on-site work needed for the closing of the joints and, the lack of a systematized solution for the sloped roof which is left to be solved with the available industrial materials and the will of the user.

They all show high grades of openness from the point of view of its modular designs, allowing enough freedom to adapt the inherent temporal evolution, the inevitable foreseen or unforeseen uses and the voluntary transformation of its space and enclosure.

Openness has to be measured in the real grade of flexibility the system gives when it comes to building the basic design but even more when it comes to make future arrangements. Not only the spatial freedom is judged but also the actual possibility to incorporate new physical units without the need for special handwork to achieve the adaptation.

The precise design of the components, the careful resolution of the joints, the manufacturing process and the assembly methods are the key stages that require deep analysis and which define whether they constitute or not modular systems. A strict regulation of measurements and absolute coordination of elements are the clues for achieving an architectural design that

Figure 4.2 Matti Suuronen. Venturo House. Finland, 1971

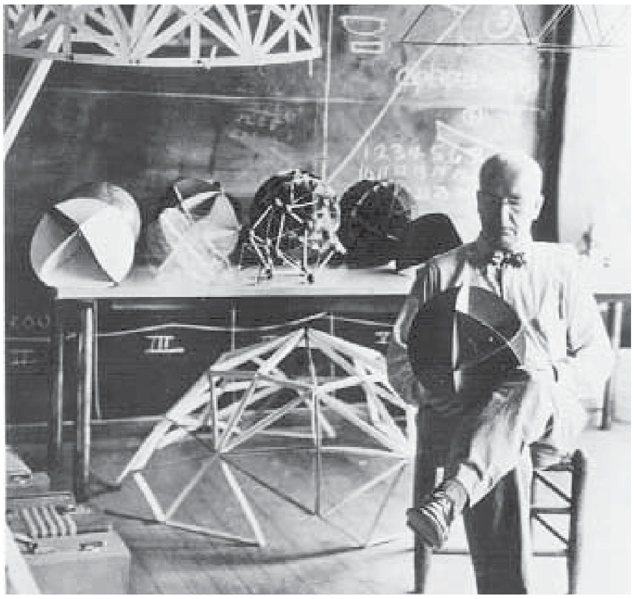


Figure 4.3 Buckminster Fuller's geodesic dome. Black Mountain College. 1949

is based on universal statements, leaving behind every singularity that could weaken the conceptual atmosphere of the design.

Inside modular system theory, there's no room for adjustments, individualities or margins of errors but reality undoubtedly calls for minor interventions that make these systems tangible and realistic. Although none of these systems managed to be a successful and widely accepted products, all constitute irrefutable historical backgrounds both for design and building industry. Despite the merits they deserve on its explorations in conceptual design and technical developments, its potential have been tinged with darkness on their lack of consolidation as mass products, to others that did succeed regarding their less stylish designs and construction quality.

The high degree of refinement achieved in these examples undoubtedly contributed to the costs not being so affordable and the general appearance did not generally satisfy enough to win the battle against other more traditional prefabricated options.

The search for systems that actively respond to natural changes in the evolution of uses or simply to the current needs of the program involved has been a difficult target to achieve since last century. Architects and designers have dedicated much time looking for advanced proposals without yet finding the midpoint between conceptual and commercially successful designs.

It's no coincidence that great characters in the history of architecture such as Buckminster Fuller, Arne Jacobsen, Charles Eames, Paul Rudolph, Marcel Breuer, Jean Prouve, Richard Rogers besides those already reviewed, have devoted years to studying and design avant-garde systems, that comply with being open and responsive. It has to be noticed that the vast majority of those examples were based on modular design and industrialized building techniques.

In the cases in which we delved, it's recognizable that the effort was put on purging the individuality of the building elements and that the focus was put in emphasizing the universality of space and the abstraction of aesthetics, also emphasizing the look for fostering the dynamics of growth and the adaptability of the system to the changes brought in time.

These systems have also in common the tectonic development which seeks to simplify the number of elements, assembly techniques and reducing on-site work to the minimum. The lightness and speed of construction make them favorable for any type of site, function and users, but that also makes them appear to be delicate and fragile, which does not always get a full acceptance by the public.

For a building system that claims for adaptability and offers exchangeability of parts to be successful to the very end, must have an uninterrupted manufacturing line that allows its availability in the market. All of these systems were sooner or later discontinued and its future condemned to obsolescence. Not being capable of being updated, reformulated and customized due to the lack of spare parts, time naturally reduced these systems to simple trials of which only very few still stand today.

Undoubtedly they all constitute major contributions to the conceptualization of the architectural projects, the systematization of the building process and the advancement of solutions for mass customization which is a great claim of our discipline. But most of it,

Figure 4.4 Buckminster Fuller's Dimaxion car prototype. Chicago, 1933

it, they represent great efforts to achieve the highest level of architectural design, in which not only function and form are contemplated but also techniques were pushed forward and the time factor is included since the very first conception.

In order to compare somehow these modular architectural systems, they are submitted to a classification by their grade of openness regarding their ability to adapt in terms of design and time, comparing also their progress achieved in prefabrication and simplicity of assembly.
The following graphic relates the three examples based on their openness of its modular design -meaning the flexibility of the system to adapt over time and functions-, and the degree of prefabrication of all the components -considering the industrialization of the building elements, the ease of assembly and the minor workforce required on-site-.

The most rated feature is the ability to incorporate changes concerning growth -the addition of units-, inner distribution -program changes over time- and material envelope appearance -materiality substitution, aesthetic reformulation-, without requiring major amounts of specific on site labor.
At the same time, those examples which are conceived as systems -concerning the design of every building component with no need of adding external parts-, are best rated for their precision and reduced number of building components, in order to lower the manual arrangements during construction and future mutations.

The systems already reviewed are put into relation between them and with other outstanding examples. These graphics intend to frame the environment concerning prefabricated architecture, placing the cases in their correspondent quadrant while comparing its main features while the other examples serve as benchmarks.

The two axis diagram locates the previously analyzed systems among some well-known prefabricated examples that happened to be titled as 'modular' at some point. The chosen examples could may have been others but this selection manages to represent solid reference points.
The three axis diagram where modular systems are qualified on its spatial, building and adaptability conditions only exposes the situation of the studied systems, helping simplify the information displayed.

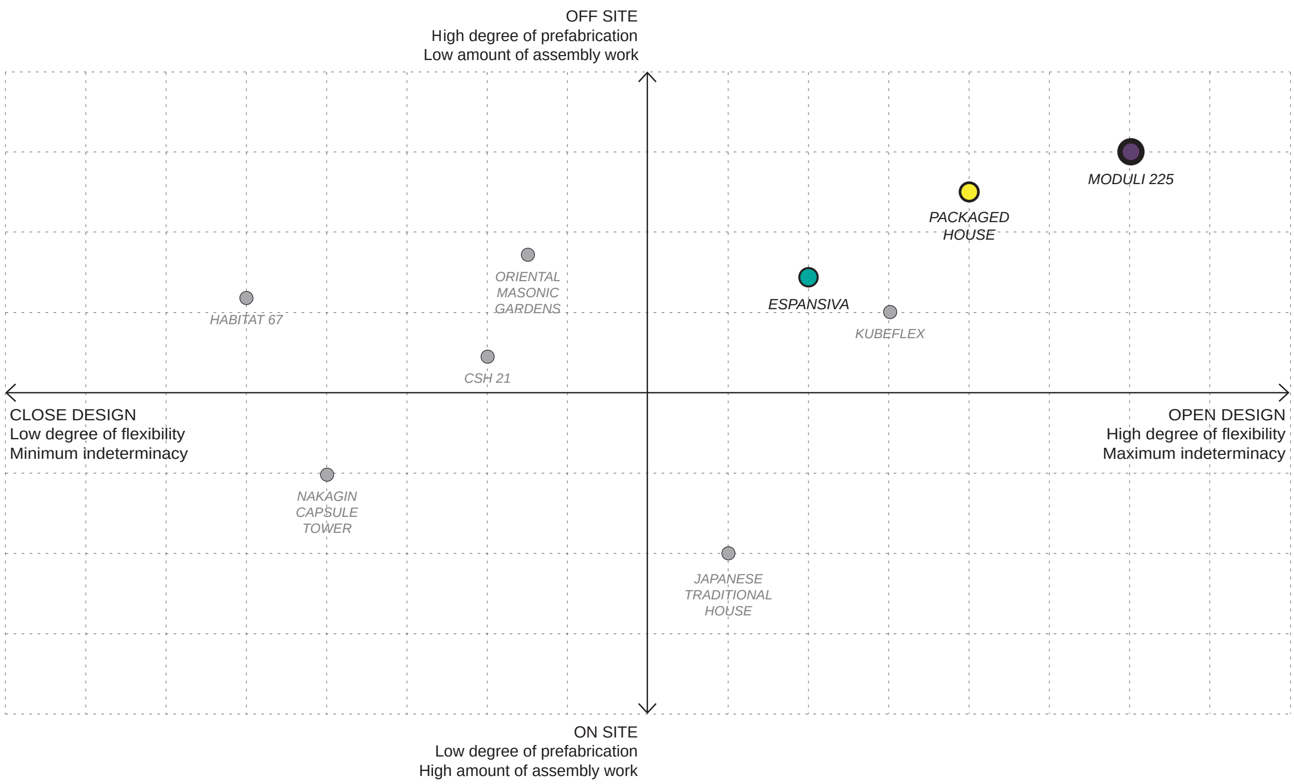
The position of each example might differ slightly depending on the fidelity of the collected data. It has to be clarified that the whole dissertation was based on theoretical information gathered from a great variety of books, essays, papers with limited access to complete archives. Any prefabricated building system claims to be dismantled in order to get to know the very core of them, or either way, they worth to be understood on site, preferably during its assembly. That way, it'd become easier to show the true implications of its physiognomy and assemblage stages helping reveal the real nature of each system.

This work constitutes a first attempt to clarify the conceptual background of modular systems in architecture, a concept that nowadays floats within a blurry atmosphere, a concept complex enough to give rise to confusion and misinterpretations. However, the formulation of the comparative analysis and its consequent conclusions, unfailingly contain a minimum amount of personal interpretation.

GRAPHIC I. The grade in which a system is considered to have an OPEN DESIGN, meaning the degree of adaptability to change and growth, is represented in the *'x' axis*. The amount of OFF SITE work, speaking in terms of the level of prefabrication of the components themselves and the amount of work off site to pre-assemble the elements (the more complete are the living units being transported to site, the highest is the level of prefabrication), is represented in the *'y' axis*.

The three systems under study occupy the right-upper quadrant, which means they have successfully proved to have a greater degree of modularity. In order to be located in that place, they must comply with being prefabricated and systematized enough to guarantee an easy and quickly assembly and provide the possibility of exchange and adapt to different functions and be flexible over time. The other cases used as benchmarks represent outstanding prefabricated examples that somehow flirted with the concept of modularity in some stage of their design process, failing to be real modular systems, could be either for not sticking to a master modular grid or not being prefabricated or adaptable enough.

The *Moduli 225 System* shows the highest level of prefabrication and flexibility. In addition to having a highly refined component design, it enables the growth of its four faces, offering plenty off variations within a clear modular grid, in which the enclosure and partitions made out of prefabricated panels can be freely combined. Its flat roof helps reduce the work on site when it comes to add new units. Foundations happen to be independent and adjustable to meet any condition of ground not needing much site preparation. Assembly is through simply hidden joints without the need for skilled labor. The general aesthetics remains abstract and refers to a universal modern language.



JAPANESE TRADITIONAL HOUSING
Japan

Modular open rooms: Tatami mat unit of measurement (jō) for room arrangements 180x90cm

HABITAT 67
Moshe Safdie
1967 Montreal, Canada

Prefab concrete units arranged in various combinations, lifted and placed on site

NAKAGIN CAPSULE TOWER
Kisho Kurokawa
1972 Tokyo, Japan

Lightweight steel room capsules plugged to on-site concrete towers

ORIENTAL MASONIC GARDENS
Paul Rudolph
1971 New Haven, USA

Factory made mobile room units placed on site, pivoting in pinwheel formation

CASE STUDY HOUSE #21
Pierre Koening
1957 Los Angeles, USA

Open plan, steel frame structure (I, H profiles), prefab steel deck enclosures

KUBEFLEX
Arne Jacobsen
1969 Archibo, Denmark

Wooden cubic room units Module 3,36x3,36 m to be combined in multiple ways to comply with housing needs

GRAPHIC II. The following three-dimensional graphic involves the 3 aspects that were used to characterize the modular systems in architecture. As seen before, the OPENNESS of its design and the degree of PREFABRICATION of its components are represented in the '*x'* and '*y'* axis respectively. The three systems, Espansiva, Packaged House and Moduli 225, are now put into relation on a third *'z'* axis that calibrates the ADAPTABILITY in time, meaning its capability of change and morph along with the performance requirements that may appear in the course of its lifetime.

The **maximum degree of modularity** is represented by the diagonal vector which requires complying with the highest degree of open design, the highest degree of prefabrication of its components and assembly off-site, and the maximum capability to adapt and be reformulated over time. Each case shows here its strengths and weaknesses, being each one qualified based on the graphic and theoretical material available.

The system *Moduli 225*, for its neutral and universal conception manifests having a greater degree of modularity, being the one which better fulfills simultaneously with the three categories. The *Espansiva* system demonstrates to deal with certain shortcomings when it comes to grant design flexibility due to the high definition of the living units, being suggested the correspondent uses. However, it theoretically proved to be highly adaptable over time by the simple addition of new units, or otherwise, its removal. On the other side, The *Packaged House* system is naturally undefined, highly flexible on its conception and adaptable to multiple purposes, scales and places. On the contrary, the fact that its gabled roof solution is solved on site makes the system hard to be easily transformable both on size and form.

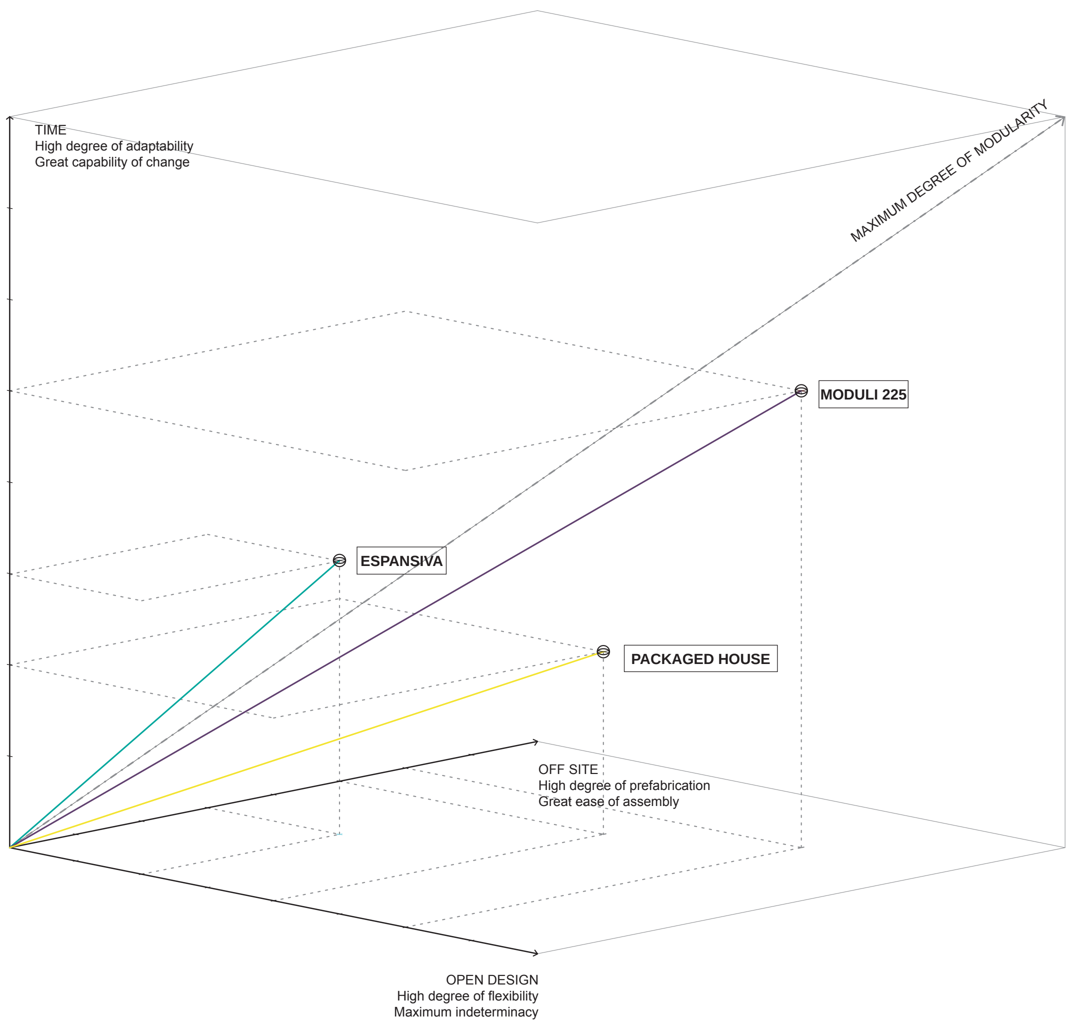

TIME
High degree of adaptability
Great capability of change
MAXIMUM DEGREE OF MODULARITY
MODULI 225
ESPANSIVA
PACKAGED HOUSE
OFF SITE
High degree of prefabrication
Great ease of assembly
OPEN DESIGN
High degree of flexibility
Maximum indeterminacy

Figure 4.5 Kazuyo Sejima. Room permutations studies for Gifu Kitagata Housing Complex. Japan 1994

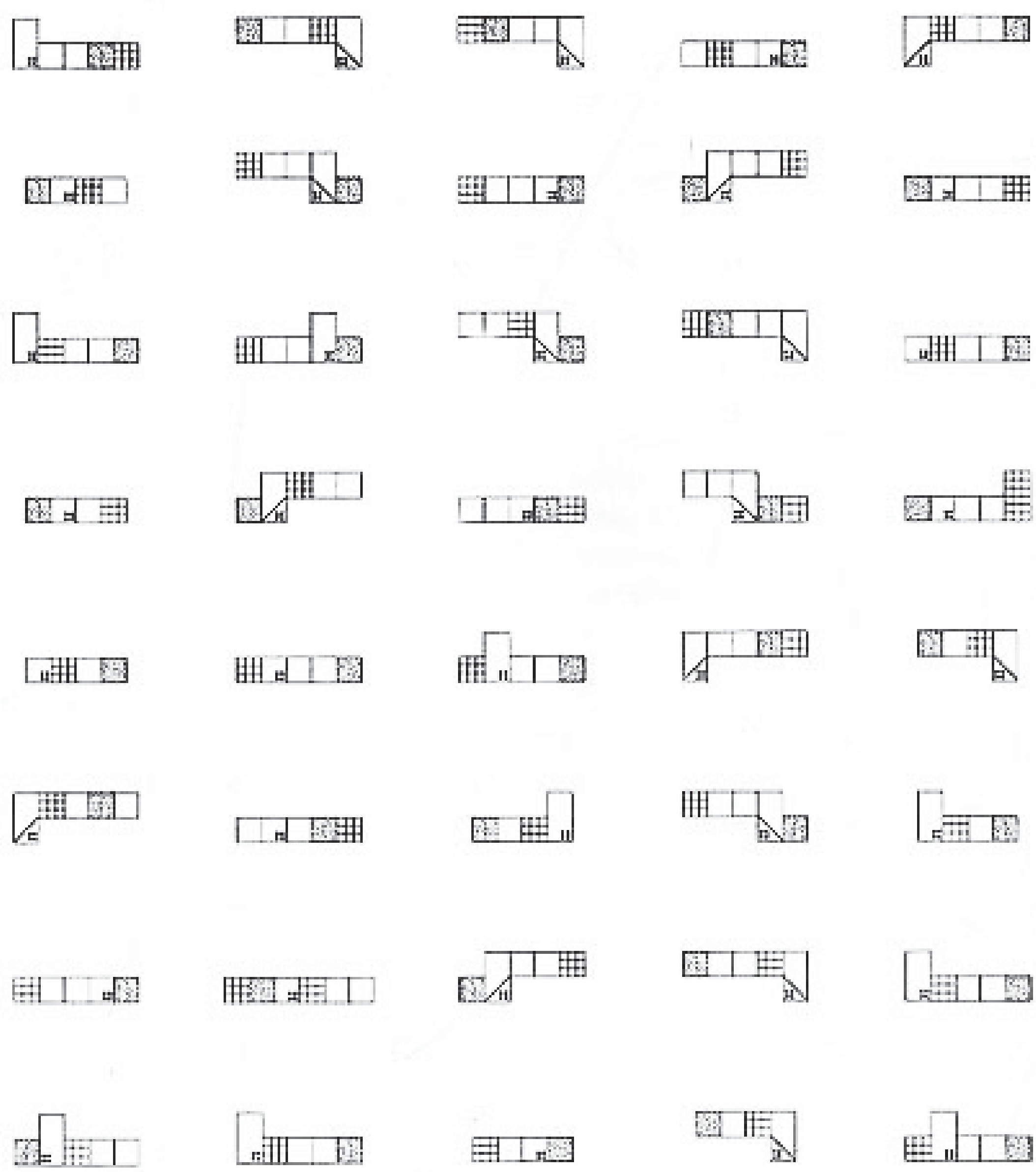
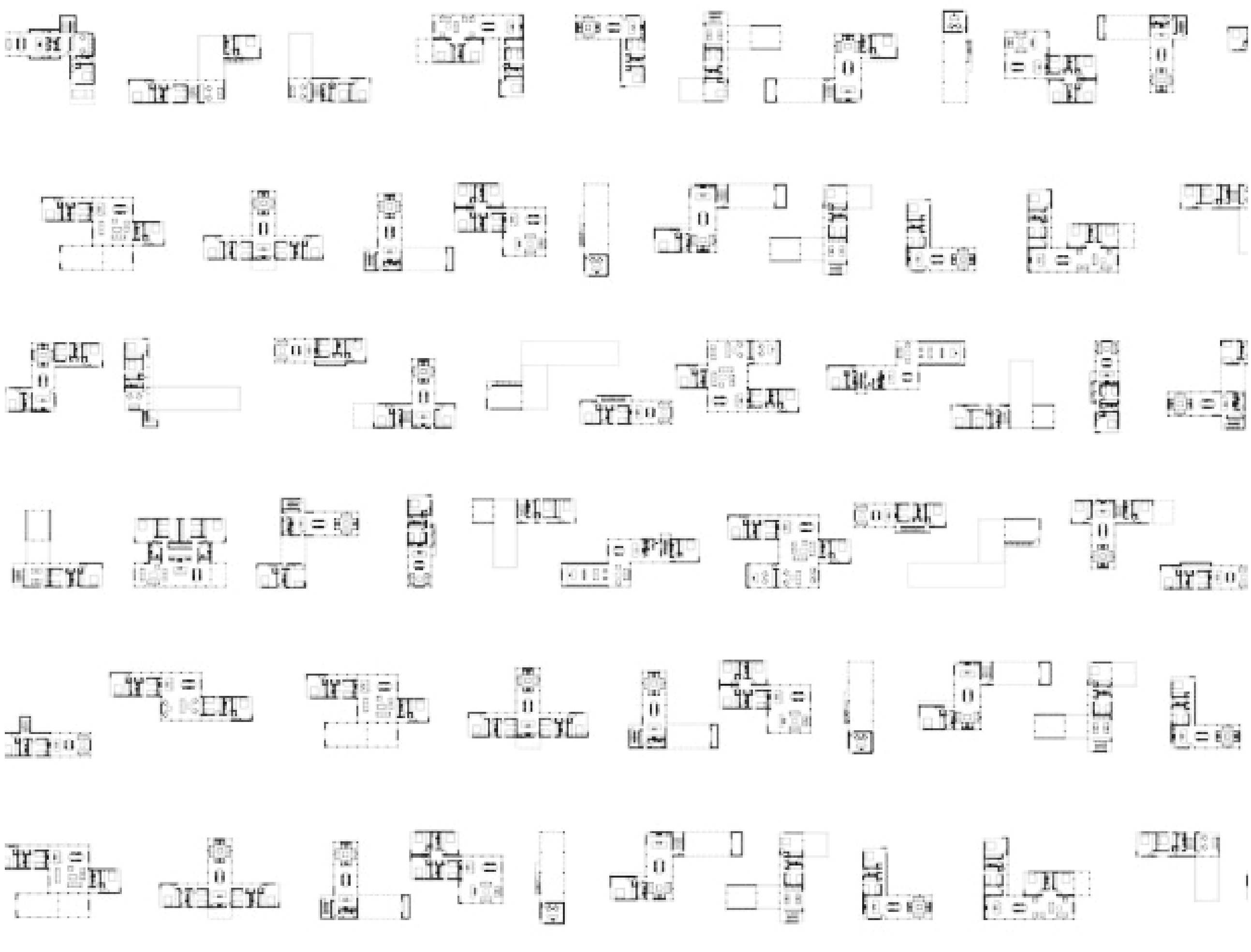


Figure 4.6 Resolution4 Architecture: Modern Modular Home Plans (cover image)



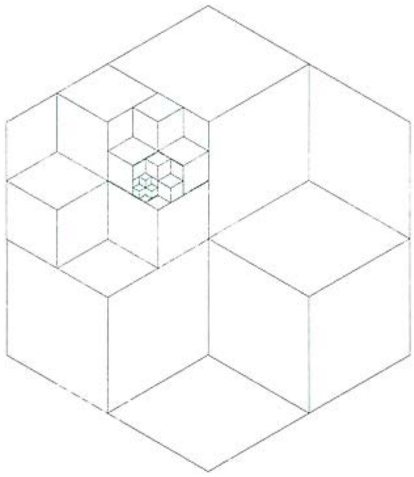


Figure 4.7 Minimal geometric compositions /geometrydaily.tumblr.com

4.2 CONCLUSIONS. Modularity in the broadest sense of the word refers to a supreme order that slips into every level of the architectural design. Implies a set of rules that displays a game of hierarchical establishments, at the same time rigid and flexible, open and closed, compact and extensible.

The attribute of modularity evokes a very disciplined design that focus on an extreme coordination of the parts involved, seeks the highest precision on the components' design, shows devotion for the definition of every construction detail, bets on a simple and effective assembly and it's totally committed to the abstraction of the aesthetics. What modularity actually represents is the spatial indeterminacy that gives infinite richness to the architectural project and freedom to the users' configuration. Its main virtue is the variability that promises by the countless combination of elements and diversity of spaces.

The challenge lies in how much variety can be achieved with such amount of imposed constraints and restrictions that are placed on the game board; this duality distinguishes modular systems among others and surrounds them with an atmosphere of pragmatism and maximum expressiveness simultaneously.

The analyzed cases, have served mainly to define the conceptual field where modular systems are framed. Each has embarked us in its own research line, showing off its strengths and weaknesses.

Modular systems, to fully comply with its definition, must strictly meet all the requirements mentioned in the course of the study. In addition to show a clear hierarchical structure that masterfully organize the whole design and set the logics of the phases -open design-, also have to develop an inventive set of building elements that favors the interchangeability -prefabricated building system- through easy assembly methods that minimize hand work, limit the incorporation of singular pieces and allow the future mutations of the basic construction -adaptability to change-.

The main contribution of the Moduli 225 system the universality of the compositive space that provided the highest degree of indeterminacy, the refinement of its constitutive elements and the exquisite and abstract aesthetics. The Packaged House helped oversee the insights of the genesis of a building system and the issues involved in the way to acquire excellence in the manufacture process and a consistent flawless physiognomy. The Espansiva showed how to overdo the architectural physical dimension in order to explore the unlimited possible arrangements through time that the systems allowed.

Each example was chosen to help describe altogether the scope of action and potentialities offered by this particular family of systems. It's also mandatory to point out that the transition from the theoretical and abstract schemes to the real dimension of building methods, actually deserved an extremely careful study that wasn't always successful. The staging of each system called for countless design reviews, totally necessary for getting the refinement that claimed these high-standard prefabricated systems. Each happened to find their own weakness when it came to face the site real conditions. To meet the real features of space and materials, every systems somehow must bend and give up some grade of their theoretical rigidity.

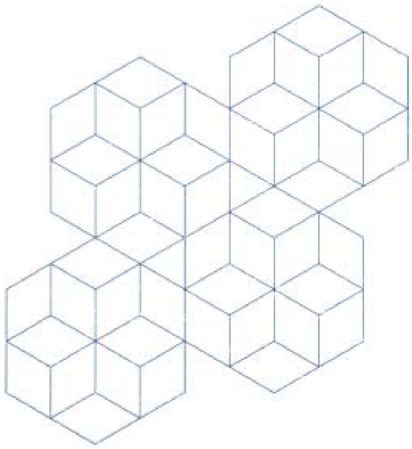


Figure 4.8 Minimal geometric compositions /geometrydaily.tumblr.com

However, even though each system loses itself some degree of precision in order to comply with its building environment, still these systems are offered as adaptable to the circumstances of the program and uses, to the aesthetic preferences of designers and owners, are capable of enable both growth or reduction possibilities, all promote the ease of the replacement of parts and ensure an effective assembly, show respect for the place where is meant to be inserted and claim for a significant cost reduction due to the industrialization of the whole.

For these all attributes, modular systems are still examples that ought to be reviewed, especially those particular cases that have exceeded the mere constructive boundaries to embark on deep conceptual trips, in the look for understanding the built object as a mean of expressing ideas of great value for both architectural culture and construction, tirelessly seeking to access to fair solutions that meet the real needs of the everyday life and consumer's will.

The customization of our living spaces must be accompanied by designs that certainly allow the exchange game, sustained by an industry that does not discontinue the ongoing production in order to prevent the devices become obsolete and meaningless. Like any manufactured object its market value promotes the sustainability of the production and continuity of output and as a consequence, fosters the constant updating and improving of the products, achieving over time access to a wider audience and consolidation of its costumers acceptance. Manufacturing costs and the absence of an economy of scale constitute still a big issue.
Although the ins and outs that involves the constructive act itself have unfailingly to be considered, the adventure that implies the development of modular systems provides a broad conceptual richness, which certainly limits the aesthetic whims towards an architectural design that exceeds the boundaries of the discipline. This theoretical exercise pushes the limits of the envision of architecture, generating dynamics that need feedback from multiple areas involved. The design becomes a complex game board of infinite combinations, where the construction elements are shown in their greater expression and spaces are the true protagonists. Time is a key factor and the result is unpredictable and indeed changeable.

Modular systems rises over conventional thinking to seek beyond the limits of new possibilities that get the architecture closer to the users and respond to the inevitable transformations of contemporary lifestyle as living organisms does.
Modularity, after all this research, still remains as an adjective that can be applied simultaneously to multiple layers of an architectural design and be measured on its degree of implication. The highest engagement with this condition would result in architectural systems highly industrialized that offer great indeterminacy and adaptability. The lowest commitment with this feature end up in architectural designs as product of more traditional creative processes.

Classification standards selected are not absolute, nor are the only possible ones, but they managed to accurately describe the features that best represent the modular systems as singular events in the history of architecture design.
Modular systems in architecture represent exquisite creative processes of great conceptual value that left so far a powerful legacy.

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Reunido el Tribunal calificador en el día _____ d _____________ de___________

en la Escuela Técnica Superior de Arquitectura La Salle de la Universidad Ramon Llull

el/la alumno/a *Cecilia Lema Scarsi*

expuso su Trabajo Final de Máster, el cual tiene por título:

"MODULAR SYSTEMS IN ARCHITECTURE. An overview of modularity through case studies"

delante del Tribunal formado por los Drs. que firman a continuación, habiendo obtenido la calificación:

Presidente/a

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