PATTERN AND SYSTEM

a speculative approach to modular design

Merel van Casteren

Abstract - Modular architecture is rising in popularity, Contractors are partnering with architects to create commercialized modular systems, that are offered as a product fitting a range of possible projects. Computer-aided design and parametric modelling offer ways to further systematize architecture, with a possible future role set out for design in partnership with AI. This research builds on existing theories of systems and patterns in architecture to form a new basis for the design of systematic architecture, using a process of patternmaking. Pattern-based design becomes a tool for finding flexibility and range within a modular system. Using the speculative design method, a scenario is sketched where the design and construction process is fully modular and commercialized. Centralized factory production of timber modules paired with digitally aided design allows for a highly efficient modular building process. Architects in this scenario take on the task of communicating between computer and designer, selection and creation of the design brief and the creation of a design system and pattern.

Keywords: patterns, systems, parametric design, modular architecture, digitalization

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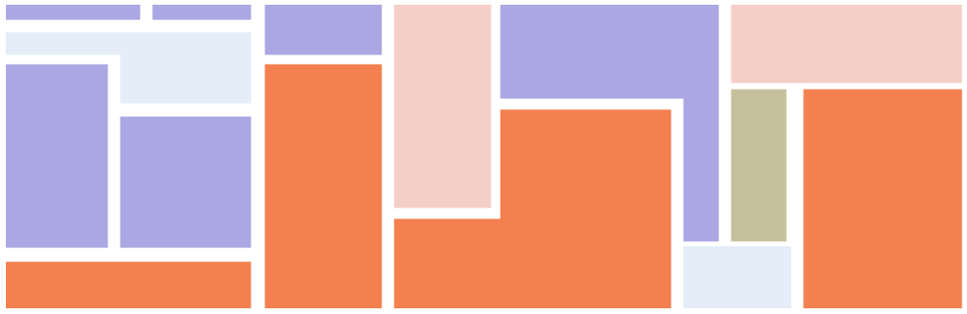

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I. Introduction

The municipality of Amsterdam is planning to expand by transforming industrial areas into dense neighbourhoods. The Minervahaven lies adjacent to the residential Spaarndammerbuurt and just North-West of the central train station and Westerpark. This former harbor was part of a timber industry that ran along a large part of the river, which has slowly made way for creative industries and office buildings. As the Amsterdam docks were expanded and rough industrial areas moved further up the river, areas like the Minervahaven became attractive options for city expansion. The existing aim is to create a dense 'urban mix', integrating the currently settled industries with a residential plan (Gemeente Amsterdam, 2021).

The municipalities aims require a different perspective, finding new construction sites on top of existing buildings. This practice of 'topping-up' is increasingly sought out as a solution to densify. Modular construction companies play into the specific demands that accompany topping-up projects, with a growing industry trend as a result. The rising popularity of modular construction is aided by digitalization and new possibilities for industrial prefabrication. Engineered materials like laminated timber make this process possible. Timber is light, has a low environmental impact and can be easily handled by man or machine.

Companies are seeing opportunities for a commercialized architecture, where an embrace of prefabrication and parametric design provides cheap, fast and environmentally forward solutions. The architectural process of these companies drastically differs from existing norms, and extremely attractive to municipalities and other parties looking for generalized large-scale solutions to a range of problems. The parametric approach allows designers to solve a range of scenarios using a single model. If we accept these changes as the future status-quo, the role of the architect would shift into unknown territory. In an interview with Dutch Profiles, graphic designer Wim Crouwel prophesises a new role for the designer in this digital age; "You will have [digital] systems, and designers will create the systems in which things take shape " (trans. Wim Crouwel in Dutch Profiles, 2012). Perhaps architects will become the creators of generalized systems in a digital space, rather than context-specific designed solutions (Schumacher, 2019).

Approaching modular architecture from this perspective reinvents the design process as a patternmaking game. Modules operate as elements within a system of relationships, which becomes the main design objective of the architect. Form follows the conventions of the system, which in the case of a modular approach influences the composition of units. While a system describes the environment of conventions and relationships in which a design takes shape, the systemization of form is better regarded as a pattern. Patterns are generated form based on a common logic, like symmetry and repetition , or a system of conventions. The Structuralist and Metabolist movements originating around the 1960's laid the groundwork for considering architecture as subservient to a system of relationships (Pernice, 2014), paving the way for a pattern-based approach to architecture.

If we redefine the design of a modular approach to the Minervahaven as a question of systems and patterns, we are able to address uncertainties around the future of modular design. How could the role of the architect start to shift through the widespread adoption of modular design processes? How can designers reclaim a role for architecture in a commercial system, working with modules as products and design as largely automated? What are the opportunities and limits of systematic design? How can a patternmaking practice help to break constraints of a modular system? Radical architects have been exploring these ideas by means of speculative design, in an attempt to uncover new perspectives and anticipate unknown futures. Through speculative design, they are able to approach complex questions by taking existing concepts and twisting them into extreme scenarios. The aim of this research is to address complex questions around the future of modular design, through a speculative future scenario. Patterns and systems form the center of this design scenario, resulting in the research question: How can architecture be approached as a system, using a process of patternmaking?

With subquestions:

1. How can pattern-based design create flexibility within a modular system?

2. How can pattern-based design facilitate a design process in collaboration with automated systems?

II. Method

The research question is addressed through a combination of literature research and research-by-design in a speculative design process. Modularity is approached as a wicked problem, with patterns and systems as resulting design objectives. The research aims to address questions around a speculative future of modularity. Complex questions involve topics like the commercialization of architecture and changing role of the architect, using pattern and system theories as guiding principles. A speculative approach is employed as a way of exploring unknown futures, which can provide new insight and help redefine the present.

II.a. Speculative design

Speculative design is a research method for asking 'what-if' questions. By exploring unknown Speculative design is a research method for asking 'what if-' questions. By exploring unknown scenarios and dealing with questions through designing, a speculative method can help redefine problems and bring forward new lines of action.

Speculative design can especially be productive in dealing with wicked problems, complex questions that address (political, socio-economic, cultural, …) systems and involve many different aspects (Galloway and Caudwell, 2018). A wicked problem has no definitive solution, and benefits from an explorative approach. Research by design helps to examine these problems by considering problem and solution as influencing each other. Rather than working from existing frameworks to a researched solution, designing as a research practice in itself can generate change within a system. In this way, it is possible to redefine existing ideas through design and come up with new courses of action. Goudswaard and Van Oosten (2022) coined the related term 'Maakkracht' to describe the power of creation for addressing wicked problems.

The goal of a speculative design is to be a catalyst for innovation or conversation. It's main challenge therefore is to remain relevant and coherent. A productive speculative design process requires a specific and extensive theoretical framework, and should avoid generalizations (Galloway and Caudwell, 2018). An iterative process with a large role for discussion and collaboration can help to arrive at a specific and comprehensive design. The speculative research method is classically split into two stages: a theoretical 'scenario' phase in which the problem is defined and a scenario is built up, and an 'artifact' phase where a solution is sought within the speculative scenario (The Fountain Institute, 2014). In both stages information is first gathered to create a broad scope, that is then narrowed through critical questioning according to the 'double diamond' model (figure 1).

II.b. Scenario phase

The wicked problem is defined in chapter III: Modularity as a Wicked Problem. Problematization further involves the outlining of context and constraints for the speculative scenario. This scenario describes the wicked problem as a speculative design question, following an extensive mapping of the problem. A literature review accompanies a process of sketching and discussing to arrive at a collage of ideas that define the scenario. This process takes inspiration from the GIGA mapping method (Sevaldson, 2011) to sketch out relationships within the wicked problem. An in-depth exploration of the scenario is conducted through literature research in chapter IV: Theoretical Framework. This chapter theorizes the concepts of patterns and systems in architecture.

II.c. Artifact phase

The artifact phase builds on the theoretical framework to design a solution for the established scenario. The case of the transformation of the Minervahaven is used as further input for the speculative design brief. This allows the speculative design phase to be carried out in tandem with the graduation design for the Minervahaven. While the speculative design attempts to answer the research question, exploring patterns and systems as a method for design, the graduation design actualizes the research into an exploration of patterns and systems as architecture.

Chapter V: Speculative design describes the artifact phase as an iterative design and discussion process, reflecting on pattern and system theory through the process of designing. According to the double diamond method, knowledge is first broadened by designing a wide range of solutions to the scenario, that are then narrowed down through evaluation. This type of knowledge is not quantifiable and therefore requires an artistic method of evaluation. Knowledge in art is used to supplement this process: "Art does not aim to provide definitive answers but rather to present a diverse spectrum of (im-) possible viewpoints on the current reality" (Hoberg, 2023).

The speculative design process concludes in a small exhibition, which shows the design in drawings and models in an interactive manner. The observations made during the speculative design process are concluded in a list of recommendations for the parallel design process of the Minervahaven.

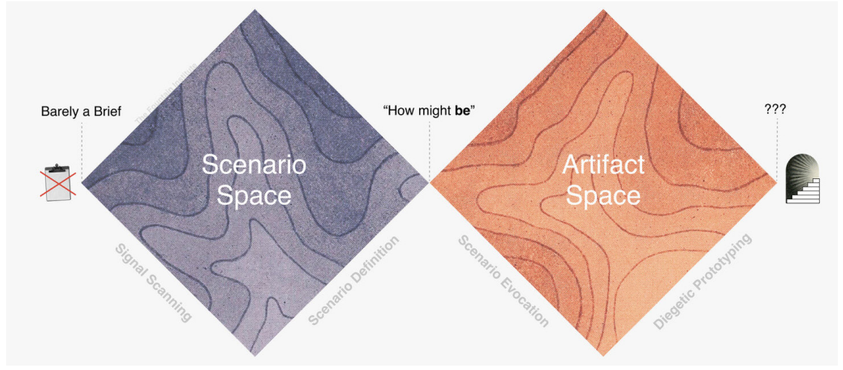


Figure 1 : The 'double diamond' process of speculative design.
Credits: The Fountain Institute.

Scenario

III. Modularity as a Wicked Problem

Modular construction is used as a practical tool, responding to a wide variety of modern-day design problems. Additionally, the rising popularity of modular construction brings along a range of concerns and opportunities. Modular design practices have the potential of radically changing the way we design and build. This chapter will introduce the predicted future of modular design as a wicked problem, impacting the frameworks in which architects operate. Using the GIGA-mapping technique, a collage of discussions around- and aspects of modular design are collaged into a speculative scenario.

III.a. Modular architecture

Modularity refers to the grouping of individual elements into modules, in which these elements are fixed. As such, a module is an operation in a system of elements. Modularity is used in architecture as a method of design and construction.

> *"The first systematizations applied to the smallest units: bricks, which had been in use since 7500 BCE. Today's system building is relevant to much larger and more complex components. The increasing complexity of systematization is demonstrated by the term "module" (modulus, Latin for measure). Whereas in earlier times, module described standardizes measurements or dimensions, such as the Japanese tatami mat or le Corbusier's Modulor, the term today stands for standardised components of an overall system. And the components can be further broken down into separate elements." (Knaack et al. 2012. In: Prefabricated Systems: Principles of Construction)*

As a construction method, modularity can provide a great reduction in construction time and cost. An architectural module is usually prefabricated, using capital-intensive automatic assembly methods, like CNC milling. Architect David Wallance explores the limits and possibilities for modular design in 'The future of modular architecture' (2021), describing how a combination of standardized design and centralized fabrication can make production and assembly of modules highly efficient, saving cost on labour and ensuring a consistent and high quality. As such, modularity implies a change in systems of production, delivery and construction. Off-site production must work in tandem with quick on-site assembly, and/or proper on-site storage. The modules must be self-supporting during shipping, while also working within the buildings structural system without excessive over-dimensioning. A shift from on-site labour to factory labour requires a different type of relationship between engineer, contractor and developer.

Because specialized production factories are necessary, shipping from factory to site is the greatest limiting factor in the dimensions of a module. Lee and Widrig (2020) distinguish two types of architectural modules: the block or unit, which is a 3-dimensional module, and modularity as a guide, which dictates dimensions and construction of elements. In the first case, a module is usually a room or block element like a kitchen block modelled to the maximum dimensions of a shipping container. In the second, modules could be shipped as a 2-dimensional flat-pack system with an optimized method of assembly. Both types of modules exceed the size of an element that can be assembled by a single unassisted worker. Assembly usually requires a crane to move the modules (Wallance, 2021). Within the assembled building we identify structures and substructures (Knaack et al., 2012) meaning the modules and their individual components, like subsets of each module. The degree of complexity within a module depends on the division of labour between site and factory.

III.b. Commercialization and customization

The rising popularity of modular systems can be seen as a direct result of increased urbanization. Growing cities are facing a housing crisis, particularly for lower- to mid-income groups. They require fast, economically viable and largescale solutions, which such systematic approaches as modular design can provide. In a modular building approach, architects and contractors often collaborate to create a system of modular solutions that can be offered as a product to clients. Companies like Elk groep, VORM and Dura Vermeer are actively building with self-produced modular products in the Netherlands. In this model, architecture is commercialized to be competitive in price and attributes like energy label and construction time with other modular products. Commercialized architecture prioritizes economics over specific solutions, by providing a generalized architecture designed in a digital space to be applied or 'fit' to a project later on.

Christopher Alexander writes in The synthesis of Form (1964/1973) about the challenges of 'fit', when applying a general practice to specific situations. He compares the fitting of a solution to context to the practice of slowly whittling down one surface to fit perfectly flush against another. Like a rough surface, a general solution needs to be carved step-by-step into fitting form. In the case of a built object the process can be simplified by means of a bridging structure, which connects context and module. The bridging structure can be adapted to create this 'fit', which allows the rest of the modular system to remain the same for each project. This is an especially common practice when topping-up an existing building with modules.

The term 'customization' is essential in describing the difference between 'fit' and specific solutions. Customization entails the changing of elements within a set system to apply to preferences or needs, rather than the creation of something entirely new. In combination with the assembly-line production of modules proposed by Wallance (2021), this becomes mass customization. Mass customization companies to offer solutions on a large scale using the same general model. Digital technologies facilitate this process by automating the configuration of different customized options within a module. McKinsey & Company (2020) prophesise a radical change in the industry following the digitally aided mass-custom and -commercialization of design.

III.c. Digitalization and systemization of form

In McKinsey & Company's prophesized change, architecture becomes fully commodified for most projects. The role of designers in this future dwindles down to a partner in the process of adapting modules to project requirements. Architects take on the role of expert on parametric processes, and are largely replaced by contractors and developers as the design decision makers. The entire process is highly integrated, working from module selection to manufacturing, transportation, assembly and maintenance with equal involvement of all parties. Lee and Widrig (2020) include robotics and 3D printers to further automate the construction process, and Negroponte (1970) even proposes an full collaboration between man and machine in the

design process. Wallance (2021) introduces the system changes caused by modular construction as the next great revolution in architecture: “When steel and concrete revolutionized building construction in the late 19th century, modern architecture emerged only through the work of architects who understood and embraced the broader implications of the new technology. Modular architecture is at a similar threshold today.” (Wallance, 2021).

Current commercialized forms of modular design seem to already be headed in this direction. Although this utilitarian architecture receives plenty of criticism about a loss of architectural quality, it also offers opportunities to free up budget for innovation and conscious design through low construction costs and controlled production. The challenge for architects seems to lie in the embracement of modularity as an architecture with its own opportunities and challenges. Modularity is a much broader concept than just the stacking of boxes and requires a different type of thinking about design to bring out its qualities.

To start thinking about the architecture of modular and digitally aided design it is important to consider the system shift it implies. In this speculative scenario architecture becomes competitive in a commercial field, using a modular system. Designing in this scenario concerns a systemization of form, finding modular systems that are able to compete on the basis of their price, properties, engineering quality and quality of form. This last aspect falls to the sole responsibility of the architect.

Collaging the discussions around the constraints of modular design, commercialization, customization, digitalization and systemization into a GIGA-map of speculations around modularity, a combined speculative scenario is found. Figure 2 depicts the GIGA-map and concluded speculative scenario as a set of assumptions and questions. The speculative scenario serves as the design question for the speculative design, elaborated in chapter five.

doors, windows
Robotics
CNC Milling
Bridging
Interior
timber
glue
bolts
services
measuring
insulation
membranes
finishes
PRODUCTION
SHIPPING
STORAGE
ASSEMBLY
flat-pack 2D
3D block module
On-site
Assembly time
SYSTEM CONSTRUCTION
crane
'static' system
Core
Stacking
structural grid
Principles
SCENARIO
Substractive
over-dimensioning
structural independency
doubling elements at corners
stiffness
open
closed
Codification
'fit'
Hybrid Cyber-space
AI-detailing
PATTERN DESIGN
Rhythm
tapestry
Symmetry
Repetition
Alexandrian Design pattern
brief
grid pattern
pattern of space & relationships
detailing
module generation
ASSUMPTIONS
economy of form
geometrics
flexibility
Scale
Voxelizing
Modules are produced using machine methods (CNC, robotics)
Assembly on-site using a bridging structure
Architect designs systems
Computer generates form
Extreme modularity: fully modular construction and design using a single system
Maximum flexibility : a single system with a wide range of applications
Super structure
Regular
network module
ARCHITECTURE SPACE
democratic
change
order
chaos
Repetition
Rhythm
axis
metabolism
chain
macaroni

DESIGN QUESTIONS

To what degree are modules prefabricated?
How are modules connected?
Which tasks are delegated to a computer?
How do computer and person interact?
What could the role of an architect in a fully modular design process look like?
What are the challenges of desgning a universal pattern?
What are the challenges of designing a universal system?
How is flexibility maximized in a modular system?
What are the qualities of modular architecture?
What are the qualities of different patterns?

Figure 2 : GIGA map

IV. Theoretical Framework

Systematic architecture works from the conviction that the process of designing is governed by rules and relationships, described by a system. System refers to an interconnected network of conventions, which in the case of architecture encompasses all interactions with, on and by a building. A modular system contains all aspects that describe the module. These include production and assembly methods, methods of design, interactions and connections between modules, the modular concept and the expression of the module. The form of the module is systematized as a pattern, a set of logical rules and aspects that compose the modules and express the system. This chapter will present a theoretical background for systems and patterns in architecture.

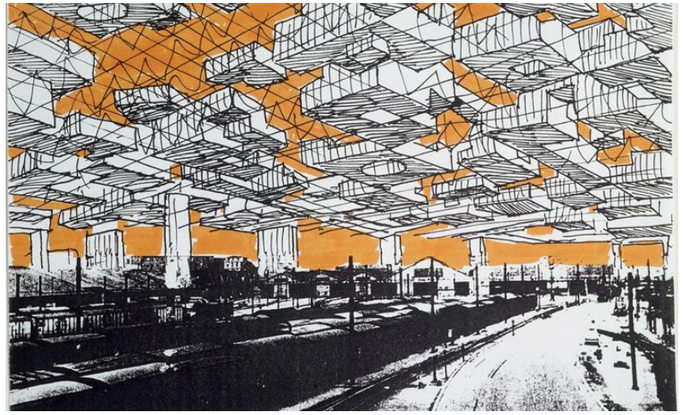
IV.a.System

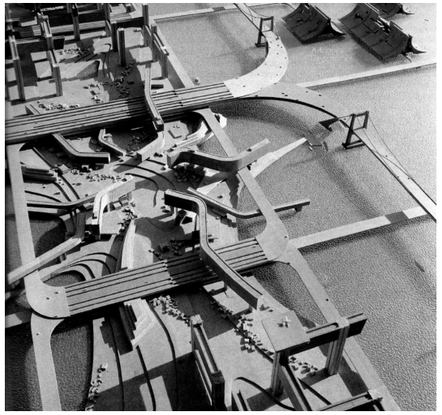
The origins for our modern concept of modularity lie with architects and movements active around the 1960's. The works of architect Yona Friedman are perhaps the most influential in terms of their reach across many different debates and fields. Friedmans Ville spatiale establishes his theory of self-determination within a democratic system of architecture, which moves freely across the terrain. Friedman sketches out his theories in speculative designs. He builds up space using principles, breaking away from context into generalized system thinking. The term megastructure is later applied to works of Friedman and contemporaries like Kenzo Tange (Friedman and Orazi, 2015), to describe a large-scale architecture that uses a systematized logic, usually a supergrid or repetition.

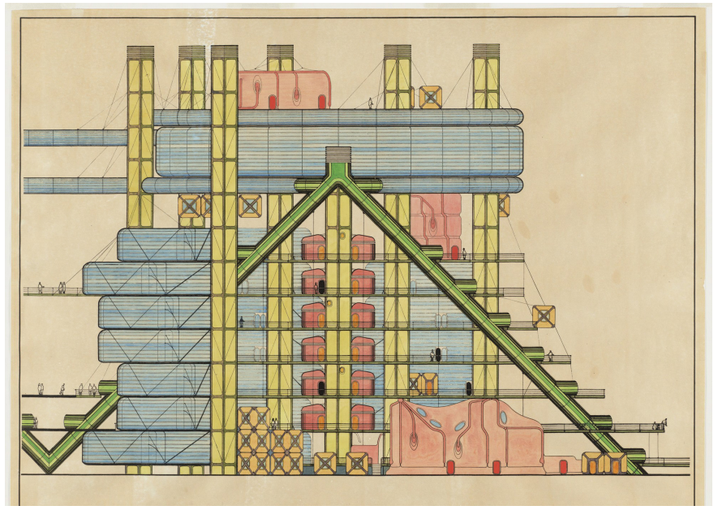
Tange and Friedmans ideas led to the establishment of the Metabolist group, with their manifesto accompanying the 1960 World design conference. The Metabolist movement was active in Japan around 1960-1970, with Tange acting as a sort of "mentor" to the group (Pernice, 2014). One of the only built projects to come out of the Metabolist group is the Nakagin Capsule Tower. The tower consists of modular 'capsules' around a central core. Modularity was used as a tool by the Metabolists for a flexible city, that is able to grow and change with time. Around the same time other movements adopted similar ideas, such as the radical architects. Archigrams Plug-In City conceptualized a moving and changing city using modules, similar to the Metabolists. The connections between modules and cores form a system of structures in the Plug-In City that supports modules and supplies them with 'food' – electricity, water, heat, supplies, etc.

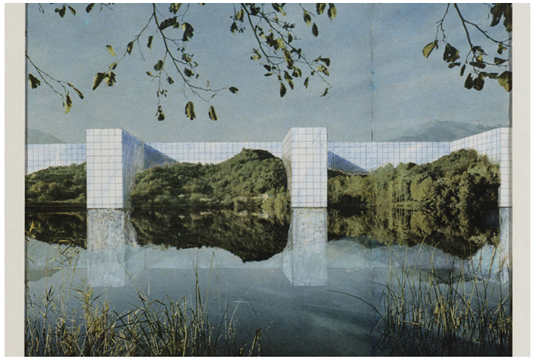
Superstudio demonstrated the idea of systems as oppressive entities in their Continuous Monument sketches, indirectly addressing how modularity can influence existing frameworks. They play with the idea of architecture as being subservient to value systems, which dictate relationships in space. Systems of architecture express social and political frameworks that hold power over the systems inhabitants, removing agency from the individual. The Continuous Monument is as much an attempt to create form without architecture, as it is a reclaiming of existing space with democratic uniformity.

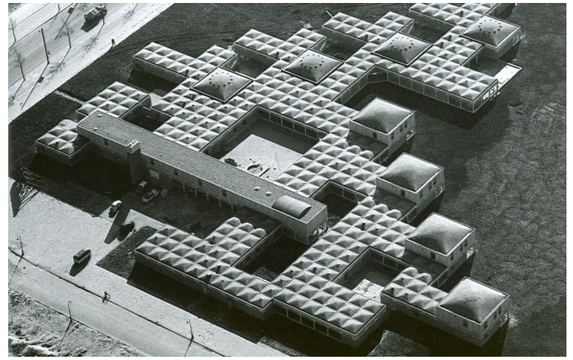
A third movement arising around the 1960's was Structuralism. Structuralist thinking considers relationships within a structure or system at the basis of design. The most important Dutch example is the Burgerweeshuis by Aldo van Eyck, which uses a regular division of space to facilitate an integration of structure with theories on social movement in buildings. Later Herman Hertzberger followed as an influential structuralist with the Centraal Beheer and Sociale Zaken (SoZa) buildings. These examples show an architecture aimed at humanity, while building on rational ordening principles. Van Eyck and Hertzberger both used

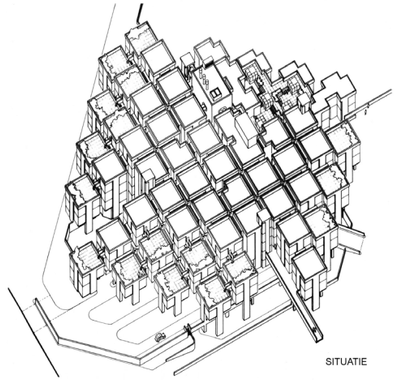












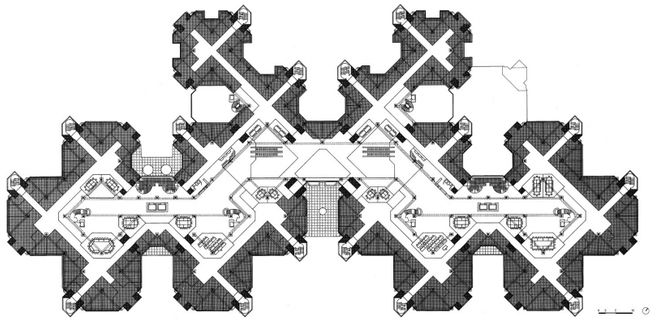


Figure 3 : Yona Friedman's Ville Spatiale sketch. The city as a flexible infill to a universal system. 1958. Credits: Fonds de dotation Denise et Yona Friedman / JB Decavèle

Figure 4 : Model of Kenzo Tange's Plan for Tokyo. A megastructure spanning the bay. 1960. Credits: Akio Kawasumi

Figure 5 : Kisho Kurokawa's Nakagin Capsule tower, completed 1972. Modules around a core. Credits: Domus

Figure 6 : Archigram's Plug in City (study). Modules facilitate a moving city. 1965. Credits: Peter Cook.

Figure 7 : Continuous monument sketch by Superstudio. Space as independent system. 1969. Credits: Superstudio.

Figure 8 : Aldo van Eyck's Burgerweeshuis, completed 1960. Stamps in repetition. Credits: WDJ architecten, photographer unknown.

Figure 9 : Isometric of Hertzberger's Centraal beheer, completed 1972. Structure divided into space units. Credits: AHH.

Figure 10 : Typical floor plan of Hertzberger's Ministerie van Sociale zaken en Werkgelegenheid (SoZa), completed 1990. Structure around connecting axes. Credits: AHH.

repetitive structures in their buildings, which form a sort of architectural pattern.

IV.b. Pattern

The first mention of the term 'pattern' as a theory in architecture comes from Christopher Alexander, in Notes on the synthesis of form (1964/1973) and A pattern language (1977). Alexander introduces the idea of a deterministic architecture that systematizes the synthesis of form. A pattern language outlines a format for the design pattern, which describes architecture as a set of interrelated elements or problems. Each such an element has a design pattern, which is a written entry that describes the elements design problem, common solutions and relationship to other design elements.

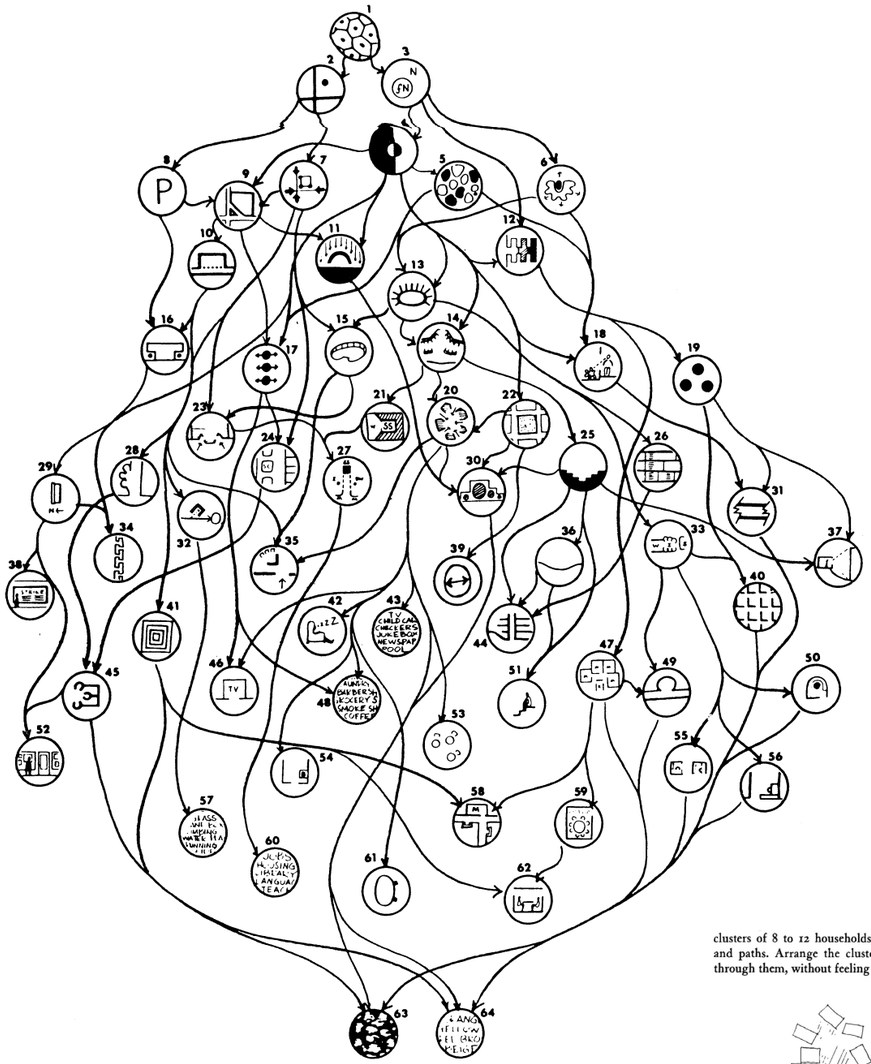
> *"The idea of a diagram, or pattern, is very simple. It is an abstract pattern of physical relationships which resolves a small system of interacting and conflicting forces, and is independent of all other forces, and of all other possible diagrams. The idea that it is possible to create such abstract relationships one at a time, and to create designs which are whole by fusing these relationships -this amazingly simple idea is, for me, the most important discovery of the book." (C. Alexander in 1971. Preface to Notes on the synthesis of Form (1964/1973))*

In his design pattern theory, Alexander laid the groundwork for a programmable architecture. By dissecting designing into a network of relationships between problems, each problem or design pattern can be examined and solved step-by-step within this network. Gleiniger and Vrachliotis (2009) describe how Alexander's formulation of the design pattern was adapted to help form the basis of parametric modelling. Using this same formulation, the structures and substructures of a modular composition can be described as design patterns in a system of relationships.

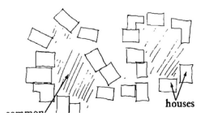
Naturally, the question arises to what degree the computer can be a collaborator in design. In 'The Architecture Machine' (1970) Nicholas Negroponte describes the Architecture machine groups efforts to create a design method where architect and computer work together as equals. The "computer-aided design system" (Negroponte, 1970) URBAN5 developed by the architecture machine group used a point-and-line based logic to construct form. In the current context, URBAN5 is best seen as a precedent to AI which is able to construct architectural drawings based on conversational prompts. Parametricist Schumacher (2019) proposes a future in which AI works as a colleague alongside the human, modelling architecture independently.

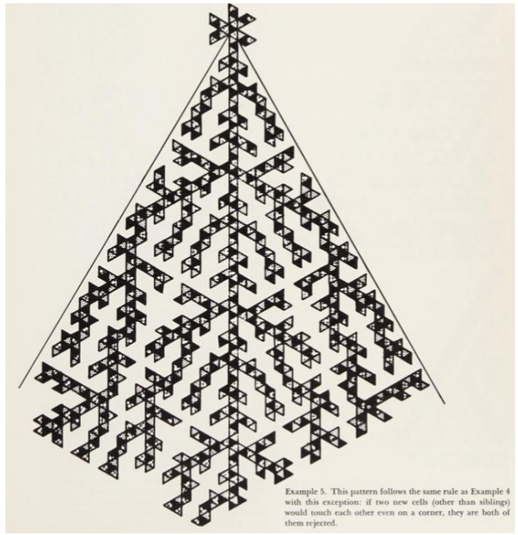
Considering patterns as a systematic synthesis of form, the basis for programmable architecture, the form is the expression of the pattern. Gyorgy dissects repetitive form in 'Module, proportion, symmetry, rhythm' (1966). They describe a common logic between patterns found in nature and created patterns, finding repetition, symmetry and fractalization as its main components. Homogeneity is not necessarily required for the recognition of pattern. Rather, a system of shared logic can create a pattern. Gyorgy further includes examples of mathematical models that generate patterns using geometric stamps, according to a set of rules as input. Different geometries create a range of possibilities, with parameters like starting geometries and order of generation conclude in different patterns. Yona Friedman uses a mathematical basis for patterns in Toward a scientific architecture (1980) to propose a pattern-based architecture, which generates form from a "repertoire" (Friedman, 1980) of geometric shapes and calculations to create a plan. The basis of this method shares logic with Alexanders Design pattern, but instead focusses on pure form over system. Both propose pattern-based design as a way of systematizing, while retaining a large flexibility and range of form.

Pattern as form is used as a tool by several notable artists and architects. Kengo Kuma works with Japanese decorative patterns as design tradition, adapting these into filigree structures (Liotta and Belfiore, 2012). Artist Peter Struycken explores systematic processes through digitally generated patterns, blending programming with art (Blotkamp et al., 2007). Ellsworth Kelly similarly systematizes art through a generative process, in which he eliminates choice by complete randomization. Colours for a Large Wall is a well-known piece made with this method. Although the piece plays with the removal of choice, the use of a grid and canvas still create a common logic that resembles a pattern.

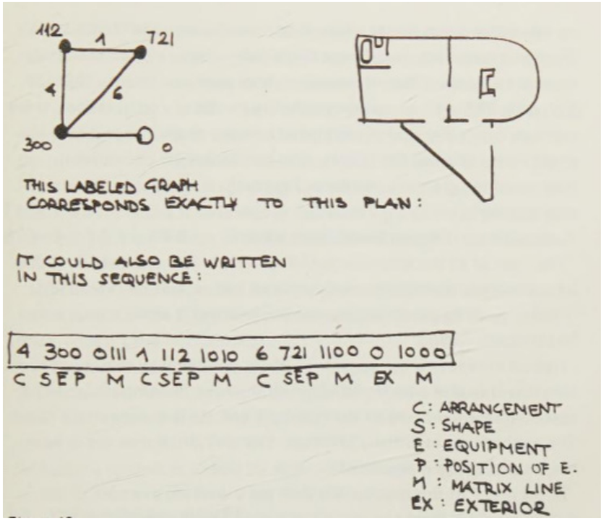


clusters of 8 to 12 households around some common land and paths. Arrange the clusters so that anyone can walk through them, without feeling like a trespasser.





Example 5. This pattern follows the same rule as Example 4 with this exception: if two new cells (other than siblings) would touch each other even on a corner, they are both of them rejected.



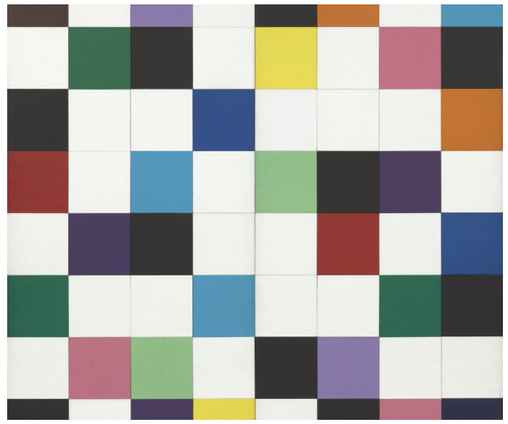


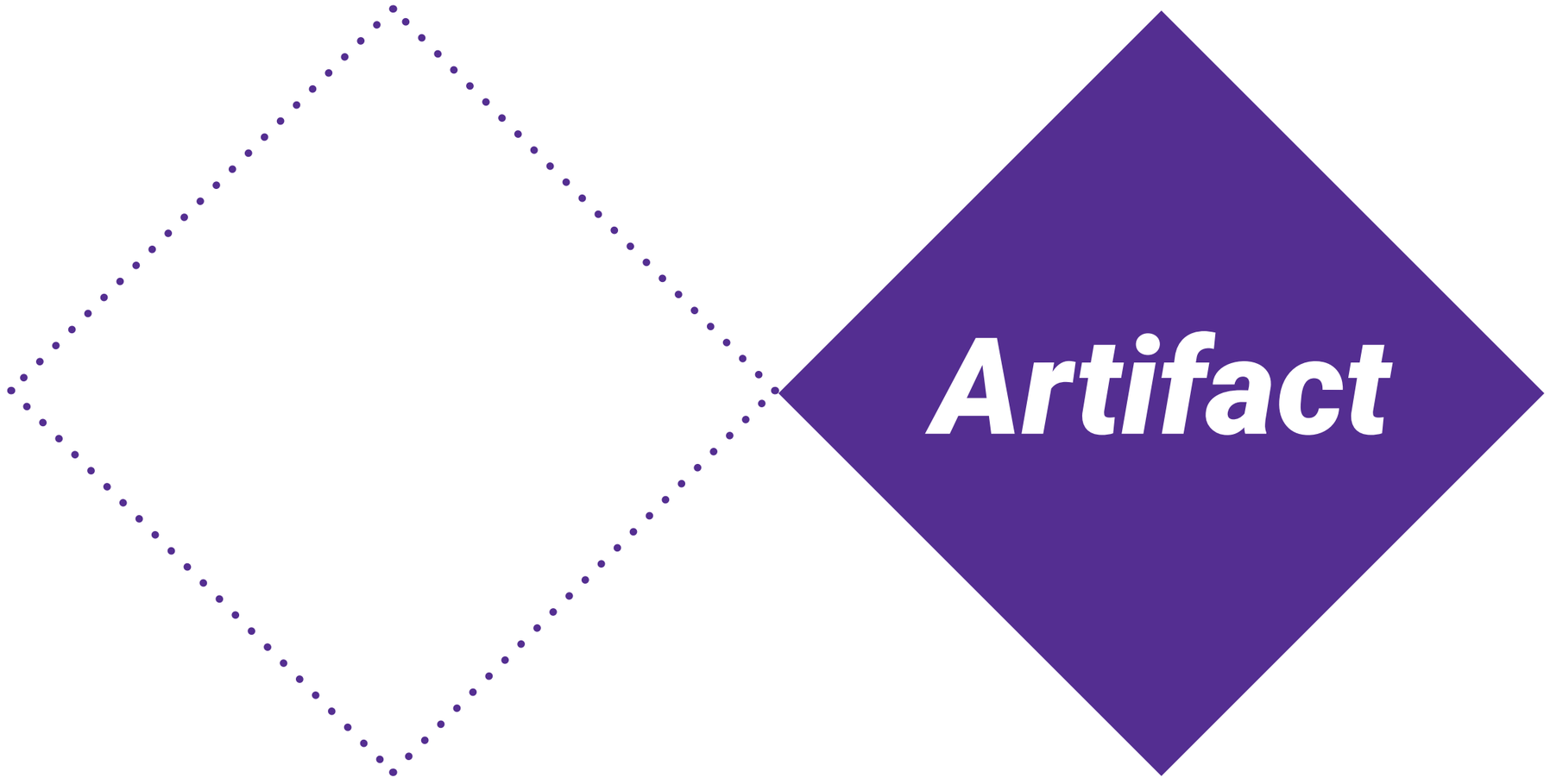
Figure 11 : Christopher Alexanders representation of a design as a network of ' Design patterns' (left) and example formulation of a design pattern (right) . From: A pattern language (Alexander, 1977)

Figure 12 : Geometric pattern generated from a point of origin (Gyorgy, 1966).

Figure 13 : Abstraction of plan as a generated element (Friedman, 1980).

Figure 14 : The interface of URBAN5. Form is generated using a voxel&point-based logic. From: The Architecture machine (Negroponte, 1970).

Figure 15 : Colours for a large wall, Ellsworth Kelly. Credits: MoMa.


Artifact

V. Speculative Design

The giga-mapping method results in a scenario describing a global design task, which yields a systematic architectural product. This is a modular building catalogue that can be applied as a flexible pattern to fit a range of design questions. An architectural product is created in a digital space without context. The objective of the designer is to create a pattern and system that function as an autonomous entity, able to adapt to demands and context as needed. Parametric design and prefabrication are essential components to a successfully adaptive system.

The determination of a design pattern is a practice of finding rules and relationships that define a flexible system. Pattern abstracts design to a description of its basic components. In the following chapters the results and conclusions found during the speculative design phase are presented, a process of trial with the purpose of determining the components that make up an architectural pattern. Each conclusion is presented as a sketch design pattern.

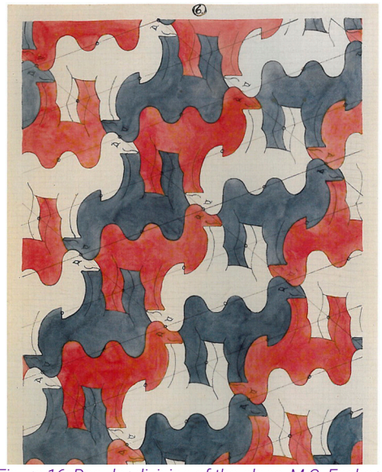
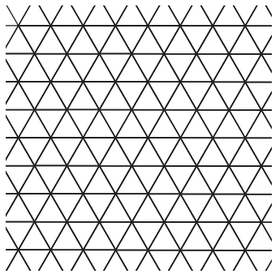
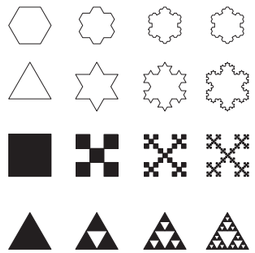


Figure 16: Regular division of the plane, M.C. Escher. Symmetry used to play with stamps.

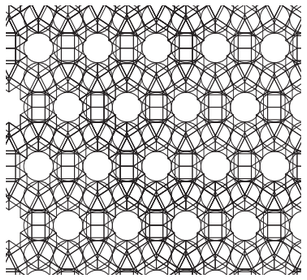
***
Pattern has no boundary or direction



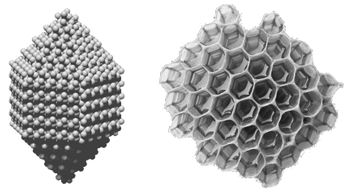
***
Scalability through fractals



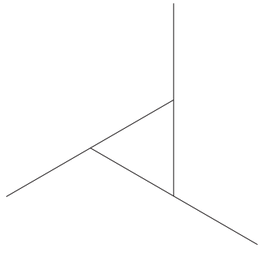
***
Symmetrical patterns



***
Regular radial structure



***
Reciprocal Knot



V.a. Radial versus Linear patterns

Most patterns found in nature take on a radial structure. This means that the patterns has a multiple of 3 symmetry axes, and no specific direction when developing outward. These patterns are able to adapt to disruptions, like impurities in a crystal structure, without having to compromise the pattern. In architecture linear patterns are often found. These have a (multiple of) 2 symmetry axes and develop in a specific direction (usually along axes of 90- or 45 degrees). The linear pattern has many qualities that make it an easy system to work with. The pattern is homogenous and can be comprised of straight elements with straight angles.

The contrast between commonality of the linear pattern in architecture versus its occurrence in nature perhaps illustrates the difference between a pattern that is designed versus ‘grown’, whether generatively or naturally. The linear pattern has many advantages that make it easier to construct, but when considering the advantages of each type as a way of organizing space the radial pattern is shown to be much more adaptable. Most significantly, the radial pattern is used to construct fractals. The ability to apply a single system across all scales through fractalization is an important advantage to the radial pattern, which makes it technically boundless in scale. Because the radial pattern does not develop in a specific direction, it is able to completely fill any type of confined area from a single point of departure. Similarly, the pattern can grow around another structure without changing its formula. When considering a pattern as a generated entity, these qualities make the radial pattern a much more suitable system.

A second important distinction should be made between symmetric and non-symmetric patterns. Regular patterns consist of a ‘stamp’, a geometry that is tessellated to organize space. The geometry of this stamp has internal symmetry, which may or may not correspond to symmetry axes within the pattern. This distinction affects how easily patterns are able to ‘stack’, if their structures overlap when placed on top of each other. Patterns can be manipulated to overlap, but because all symmetric patterns naturally stack well this type is better suited as an architectural system.

Dutch artist Escher uses this principle to morph patterns together guided by points of symmetry, demonstrated by his drawing series Regular division of the plane (fig.16).

* Voxel

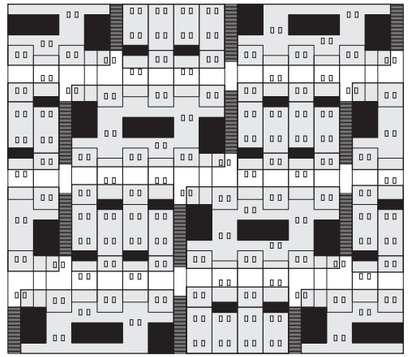


Figure 17: Example of a linear pattern (Kasbah Hengelo, Piet Blom)

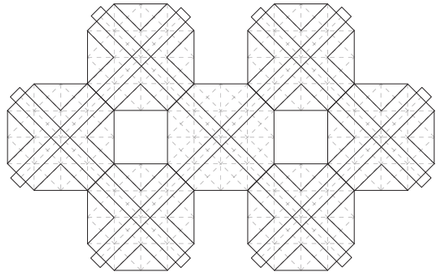


Figure 18: Example of a radial pattern (SoZa, Herman Hertzberger)

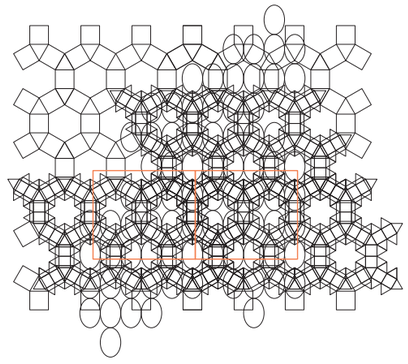


Figure 19 : Stucture of a symmetric pattern

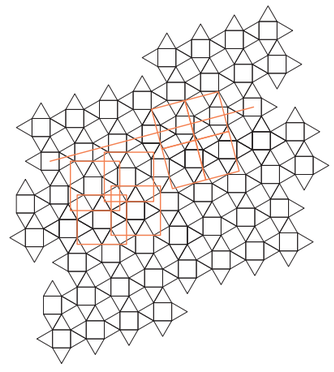
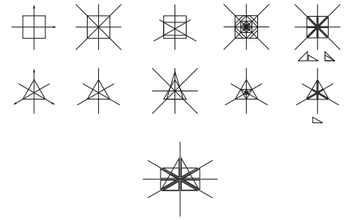
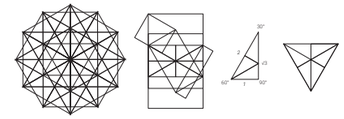


Figure 20 : Stucture of an asymmetric pattern

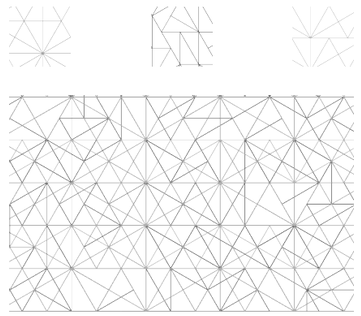
***
Multiples of 2- and 3 axes



***
Multiplicity of patterns from single geometry



***
Tesselated symmetrical pattern



***
Voxel as polyhedron with straight sides

v.b. Voxellizing space

A pattern, system or module is defined by its components. Lee and Widrig (2020) describe the voxel as the most important component in a digital(ly aided) design process. The first step to a determination of architectural pattern is therefore the determination of the voxel.

Three primary shapes are derived from Gyorgy (1966), the regular triangle, square and circle. Simultaneously, these can be seen as three methods of erecting a volume off the ground: the the portal, pitch and dome. A complete overview of all regular pattern permutations using the primary shapes is shown in figure 21. The circle is disregarded, as it is not able to tesselate and therefore is unsuitable as a voxel. Figure (22) places the geometries in space, depicting all relevant polyhedrons based off the number of vertices.

The tessellations demonstrate the significance of the stamp geometry. The internal symmetry (axes) and the number of points and sides of the stamp influence the number of directions a tessellation can grow in. Additionally, each geometry has a set of associated fractals. A voxel with the highest degree of flexibility should possess a high number of different possible tessellations and fractals.

Regular polygons can be divided by (multiples of) 2- or 3- axes. A geometry that is able to construct polygons with both 2 and 3 axes would be able to function as a base to build up any kind of regular shape. This geometry is found by morphing together the square and triangle to create a 1:2:√3 - 30°:60°:90° right-angled triangle. The right-angled triangle can create a large variation of patterns consisting of a subsystem entirely out of the same geometry. This method of pattern building is easily stackable, creating a high degree of flexibility when interpreted as a building grid or method of geometrically subdividing modules.

The right angled triangle is interpreted as a three dimensional form, which becomes the voxel. The most important aspect of this voxel is its potential to translate into a modular concept. The voxel therefore is a polyhedron with vertical sides, as modules need to be able to connect and link together horizontally. A more complex polyhedron might offer other advantages, but is deemed to be too complex to translate successfully into a large-scale applicable timber module.

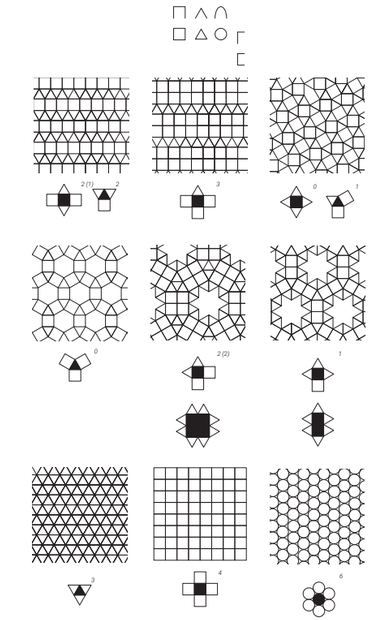


Figure 21 : Permutations of primary shapes based on connective rules.

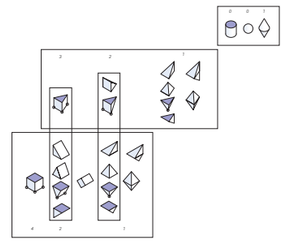
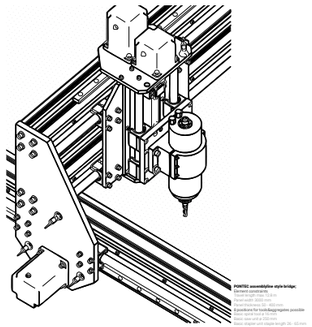
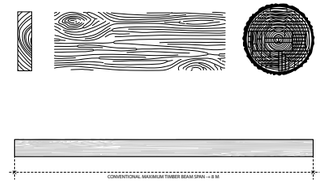


Figure 22 : Permutation of primary shapes to polyhedrons based of number of vertices.

***
CNC milling



***
Details and frames in sawn timber



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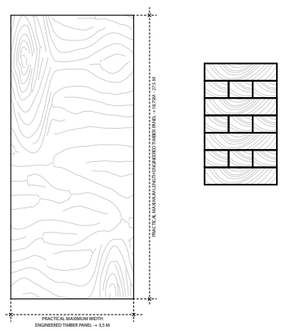
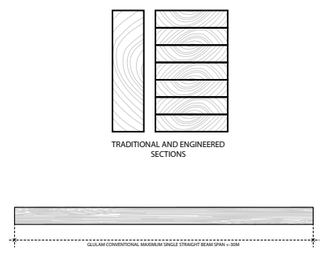
CLT panels



***
Glulam beams and posts



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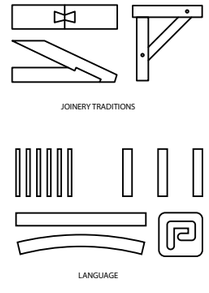
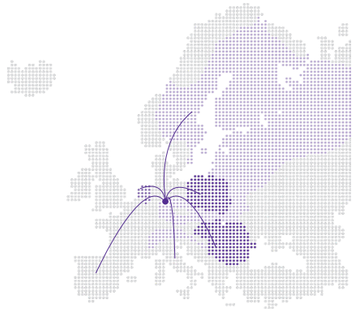
Joinery and milling limitations



***
Centralized production of prefab members

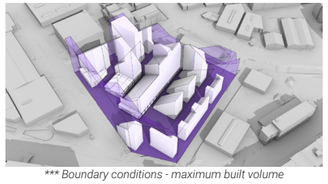


v.c. Geometry and morphology of Timber

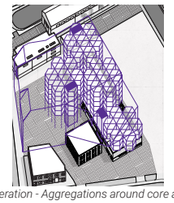
Timber posses intrinsic patterns, which dictate how a pattern system translates into architecture. A tree expands radially, and from the round trunk rectangular planks and beams are cut. Modern engineered timber is glued to create beams and panels with theoretically endless proportions. The new limiting factors become the size of the milling and transport equipment; 12800x3000x400 mm for most CNC machines and 3350x2430x6090 mm for transport (Wallance, 2021). Although any angle is theoretically possible, most timber products are milled at a 90 or 45 degree angle. CNC milling uses round bits which are not able to fully cut sharp angles.

Furthermore, Wallance (2021) presents a future in which the production of modules is centralized. They propose optimized factories that are able to create timber products in an assembly-line style, using a standardized way of working. This process integrates computer assistance to the highest degree, attempting to automate as much of the production as possible. Using standardized systems of measurement and assembly benefit this way of working, by decreasing the amount of specialized tools necessary. The prefabricated modules together form a Kit of Parts, which can be assembled on site. The speed of production and assembly depends on the complexity of each module, the degree of complexity of the modules and number of unique parts. A high degree of prefabrication speeds up construction, meaning that modules contain more components. Determining the modular system must therefore start with determining the complexity and size of the module. What are the module, system and subsystems?

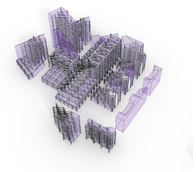
* Generative sequence



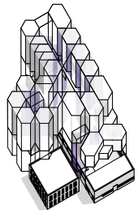
*** Boundary conditions - maximum built volume



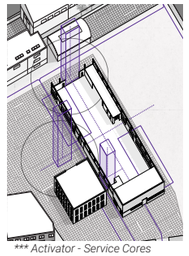
*** Linear generation - Aggregations around core along axes



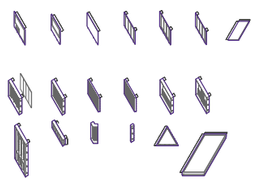
*** Medium - Superstructure



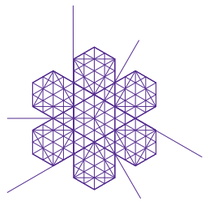
*** Manipulation - Editing the pattern



*** Activator - Service Cores



*** Detailing - Translating into modules



*** Axes - Direction of generative sequence

v.d. Generative space

Peter Struyckens Wetmatige beweging (fig. 23) paintings illustrate a pattern type based on rule and repetitive composition, but without symmetry. An applied pattern has to be reactive to its environment, and adapt accordingly. A distinction should be made between a regular pattern, which is a tessellated homogenous structure, and the chaos pattern, which applies the principles of a regular pattern but also integrates disruptions. Similar to the structure of a crystal with imperfections, the chaos pattern is based off a regular set of rules but remains able to form complex relationships with context and space. For this type, patterns are only stackable when designed point-by-point to match. Complexity is increased, which makes scaling this pattern type up a job better suited for computer calculation.

There are several ways in which a pattern can ‘grow’ or generate. Urban5 generates plans from a single starting point, similar to Yona Friedmans method in Toward a scientific architecture. The placement of each element is sequential and depends on parameters set based on proximity and adjacency to other elements. For example, element x must have a proximity to sunlight and be adjacent to at least two parts of element y. These parameters can be encoded in a database using the Alexandrian format of Design Patterns (DP). These formulate design as a set of abstractions, which allows for a system to be put in place and communicated between people and generative programs. Design patterns include such elements as the Kit of Parts and constraints like building height, fire safety requirements, proximity of functions within the building, etc.

From this database a pattern could also find an optimum fill in a space, instead of growing from a point of departure. Boundary conditions need to be formulated, within which an ideal assembly of the pattern can then be generated. Again, proximity and adjacency parameters are used to describe a network of relationships between elements, which is resolved to find an ideal aggregation with the least amount of compromise between conditions. Additionally, the last method can be reversed to find an aggregation in which all conditions are fulfilled. A maximum volume can be filled with a regular pattern, which is then manipulated to fulfil the requirements of each voxel or element within it one-by-one. This method is slower to generate however, and leads to different outcomes depending on the order in which parts of the pattern are considered. It is therefore less suited to the generation of a new pattern, but can be used to adapt existing structures.

Trials in Rhinoceros 3D using Grasshopper and Wasp show what forms result from using the right angled triangle with each of these methods and a very minimal set of requirements. A generative process using several steps, editing and layering the form is determined to be the most effective method. The pattern requires a starting point and direction to determine the priority with which elements are placed.

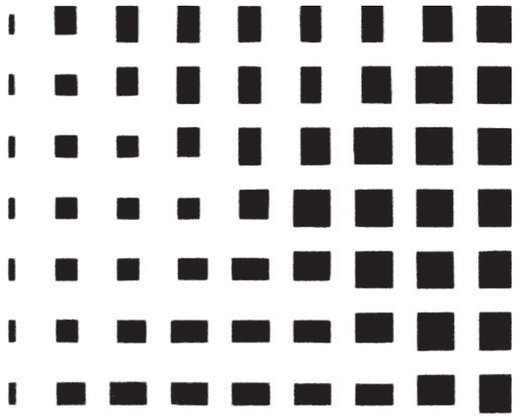


Figure 23 : Wetmatige beweging, P. Struycken. Chaos pattern generated by rules.

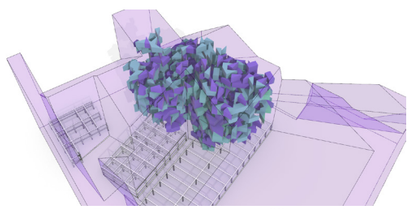


Figure 24 : Aggregation filling a volume

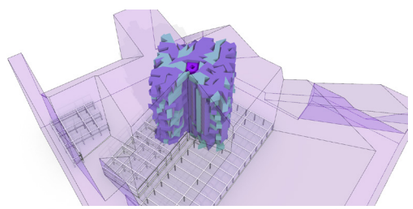
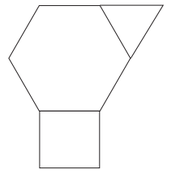


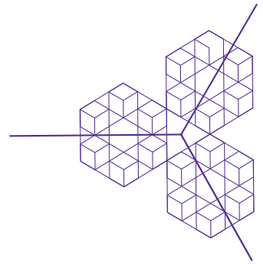
Figure 25 : Aggregation growing around core

* Digital space

***
Sectional Modularity



***
Non-symmetrical



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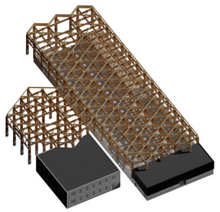
Bridging structure



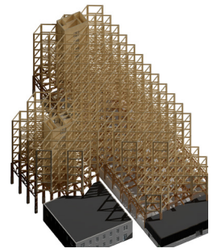
***
Stedelijk dak

v.e. Actualizing the digital

With the voxel as language, a modular system can be defined. Based off Christopher Alexanders formulation of design patterns, we can describe a modular system as a set of elements which are placed within a network of relationships, otherwise also called a kit of parts. The range of a modular system depends on the variation within- and adaptability of the kit. Dividing the kit into structure and fill results in a more widely applicable system. A superstructure of columns and beams first is erected within the confines of a set volume boundary. Using the 30-60 degree pattern grid a structural core may not be necessary for smaller buildings in this system. However, a core will always be the starting point of the generative sequence, and artery to connect circulation and building services to the ground level.

In the case where the building needs to respond to a more complex context, like topping up or on special terrains, a bridging structure is required to impose the patten on top of an existing structure. Architect Piet Blom formulated the 'stedelijk dak' principle, in which buildings are lifted on stilts to make space for communal and other city-associated activities beneath. A rigid table structure forms the base of this 'stedelijk dak', and bridges between the building and context. If the building needs to respond to an existing pattern within the context, such as another building grid, this issue can be solved within the table structure by making use of a fractalized pattern within this layer.

***
Plug-in Megastructure



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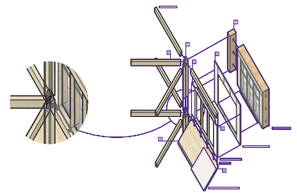
Frame and panel system



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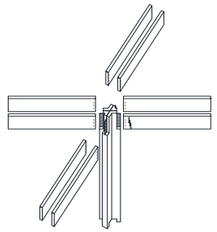
Demountability



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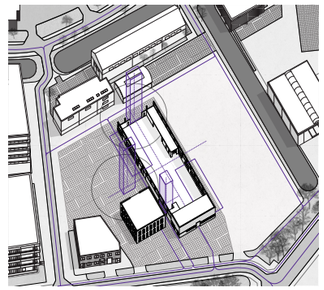
Service cores



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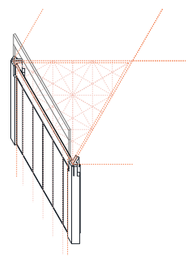
Complex modules



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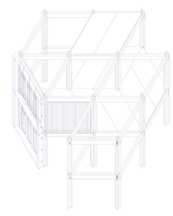
Core and Shell



VI. Conclusions

The tasks of a system- and pattern architect are identified as the determination of the voxel, a kit-of-parts system defined by parameters, generative method and method of assembly. The Alexandrian design pattern can be used as a format to encode the system and patterns as a dataset, which can be communicated between designers as well as between designer and computing system.

The widespread embracement of modular construction promises a change in the building industry. The role of architects is predicted to shift towards the creation of modular systems as commercialized products. Computer aided design, AI and robotics may become a large part of the process, slowly automating systems of design, production and assembly to an extreme degree. Projects such as the Minervahaven may be transformed with a single system solution, that is able to adapt modules to the requirements of the brief and context within a megastructure or masterplan.

Preparing for this speculative future, architects may need to advocate for the indispensability of their skills in order not to be replaced by economically optimized, uniform models. Considering patterns and systems as a design question places architects back in the centre of a commercial modular design process. Patterns allow for a systemization of form, while retaining flexibility and range in design. Using pattern and system theories, a scenario can be sketched in which the architect is the creator of a pattern language and system of architecture that has the capacity of generating space. This practice diversifies the potential of modular construction, and reimagines commercialized design systems as an opportunity for architects rather than a demise of architecture.

VII. Discussion

This research was conducted over the course of half a year, integrated with a design process for the Minervahaven. The research serves as a starting point for design, as well as a catalyst for discussion. Presented is a narrative of patterns in architecture, systematic design, modular construction and a designed exploration of who these have the potential to change the way in which architects work.

For this paper, a 2-dimensional pattern is preferred over a three-dimensional complex structure. For the sake of translating pattern into a modular system that is able to respond to the Minerva haven design brief a straight-faced module is chosen. This type of module is less complex to implement, ship, construct and design, but does have limitations as for the exploration of pattern. The most exciting continuation of this research would therefore be the exploration of an odd-angled polyhedron pattern. This form might lead to a new type of structural grid. Yona Friedmans exploration of the different types of ‘space’, especially the space-chain and macaroni may offer an additional starting point for the consideration of 3-dimensional pattern.

Lastly, patterns and systems as they are defined in this research are principally a method for communicating design principles, between people and between man and machine. The creation of a universally ideal pattern by a single designer is therefore an impossibility, as the nature of commercial systematic design relies on adaptation and collaboration. The conclusions to this research process only become relevant by their potential to incite debate, and inspire others to adapt and change the design principles presented here. This is echoed in the research method; the last step of a speculative research- and design process is always presentation and discussion. A decisive conclusion is irrelevant in this process. Rather the value of this research lies in its potential to be discussed and translated into action.

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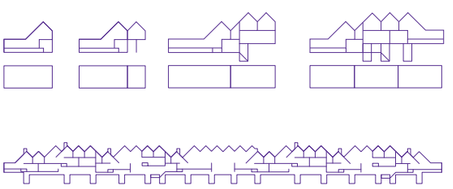
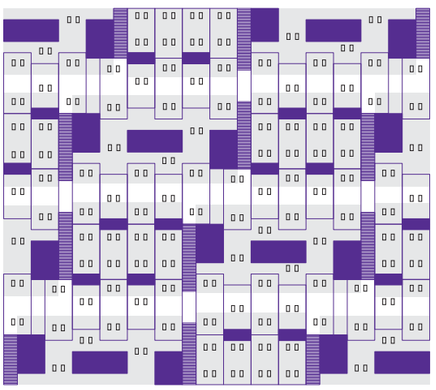
STEDELIJK DAK CONCEPT &KASBAH HENGELO

Reference project

Piet Blom

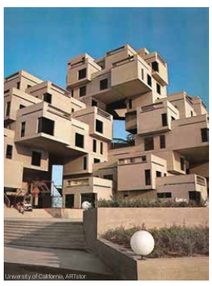


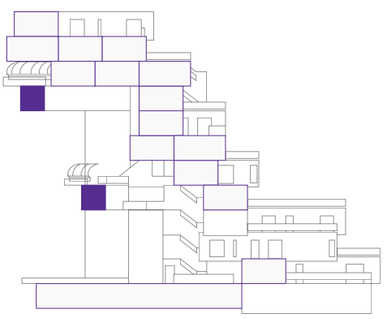


HABITAT 67

Reference project

Moshe Safdie, Safdie Architects





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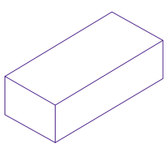

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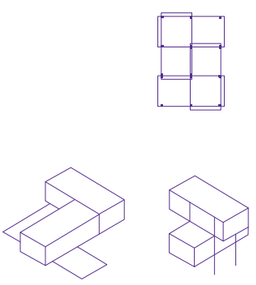

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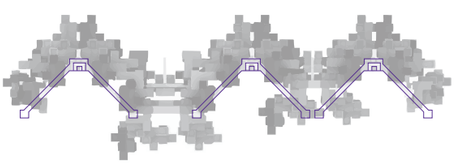
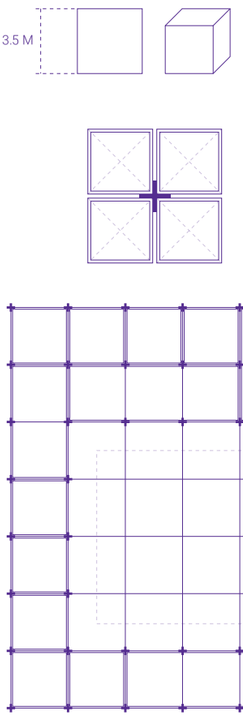


NATURAL PAVILION

Reference project

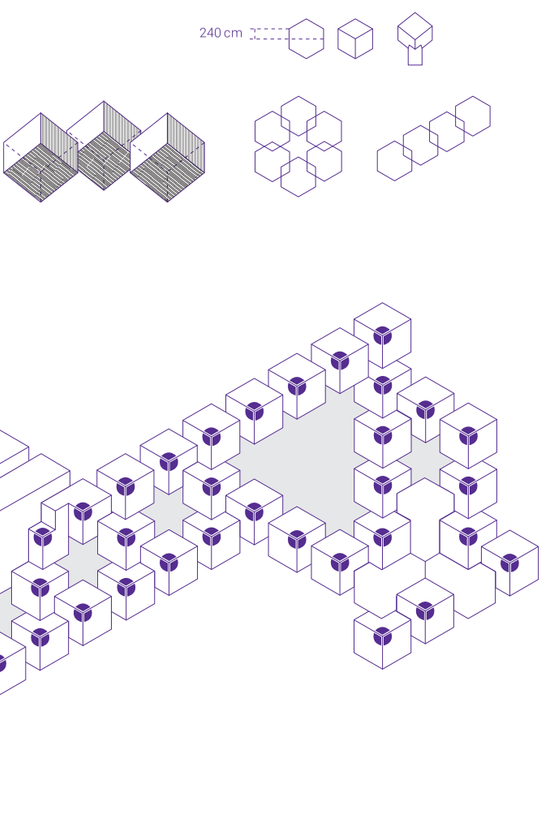
DP6



KUBUSWONINGEN

Reference project

Piet Blom

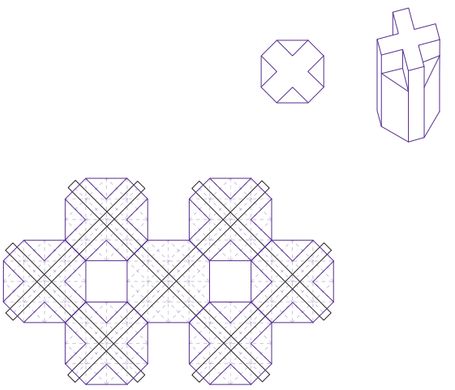


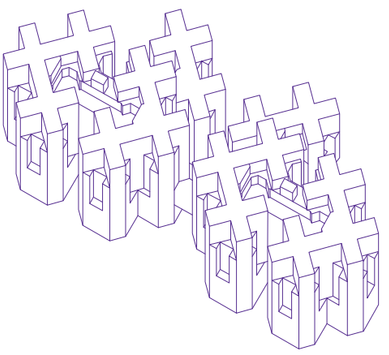
Architectural wood graduation studio
Pattern and System
Merel van Casteren

SOCIALE ZAKEN

Herman Hertzberger, AHH

Reference project

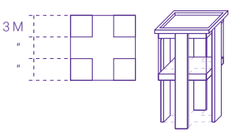


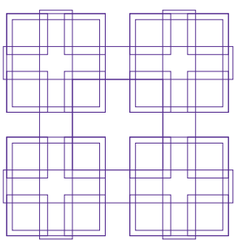


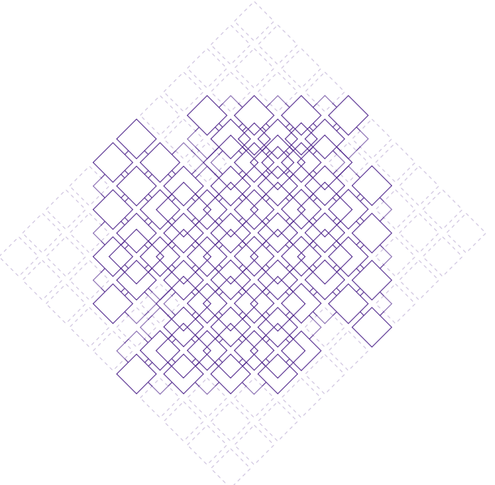
CENTRAAL BEHEER

Herman Hertzberger, AHH

Reference project



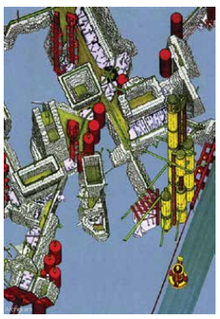


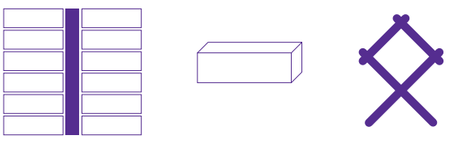


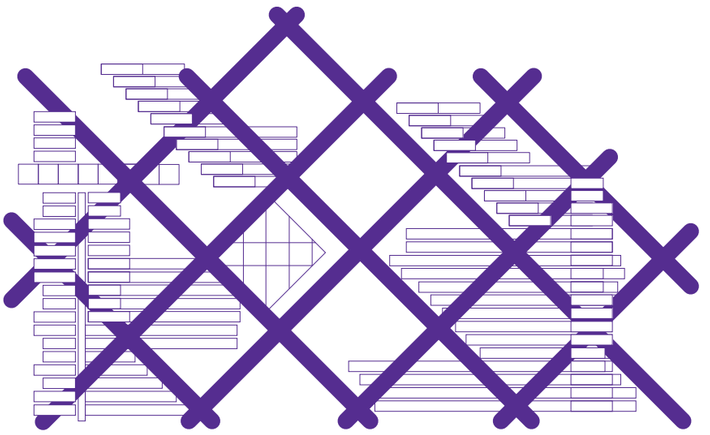
PLUG-IN CITY

Peter Cook, Archigram

Reference project



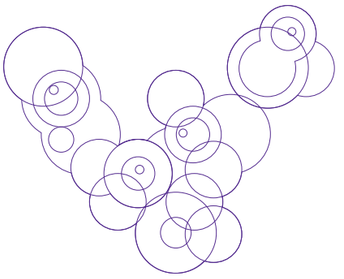


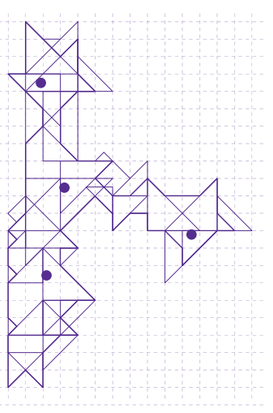


LES ÉTOILES D’IVRY

Renée Gailhoustet, Jean Renaudie

Reference project





SYLVA MODULAR KIT

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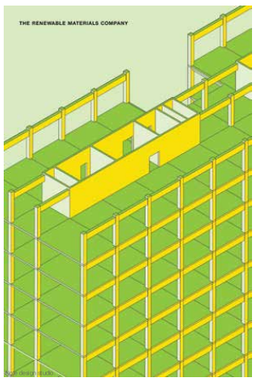
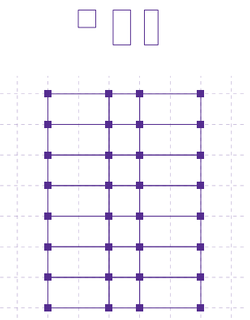
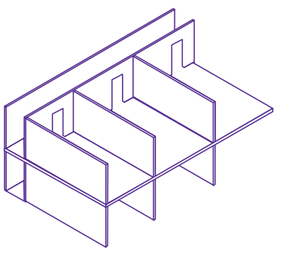
Reference project

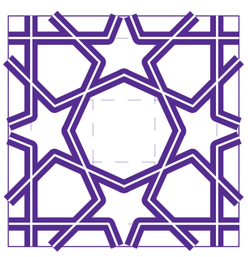




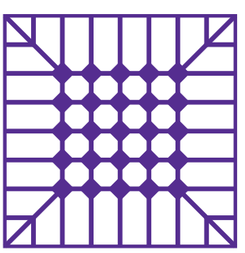


OBSERVED COMMON PATTERNS

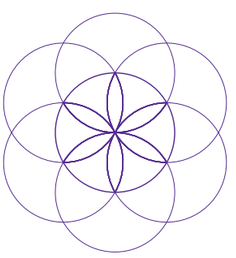
Reference project



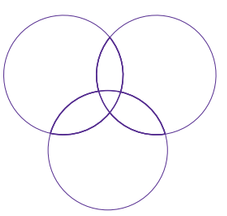
Pattern commonly found in Arabic building traditions



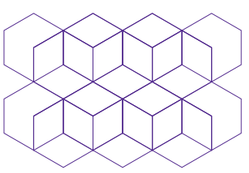
Beam pattern commonly found in Arabic building traditions



Hexafoil



Triquetra

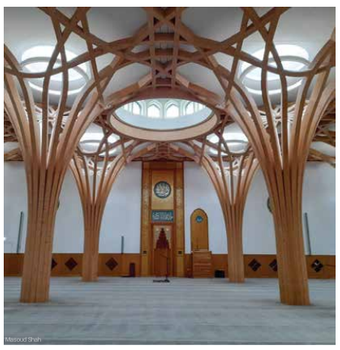


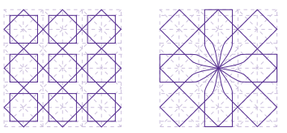
Pattern found commonly in e.g. Japanese tradition

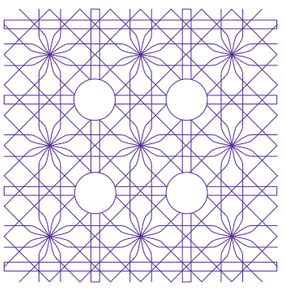
CAMBRIDGE MOSQUE

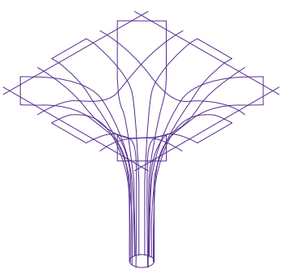
Marks Barfield Architects

Reference project





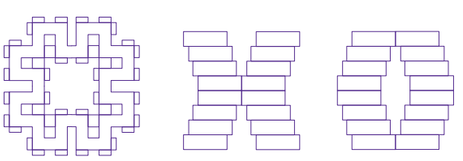


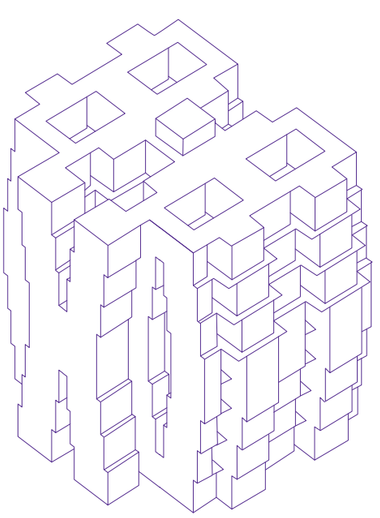


WALDEN 7

Ricardo Bofill

Reference project

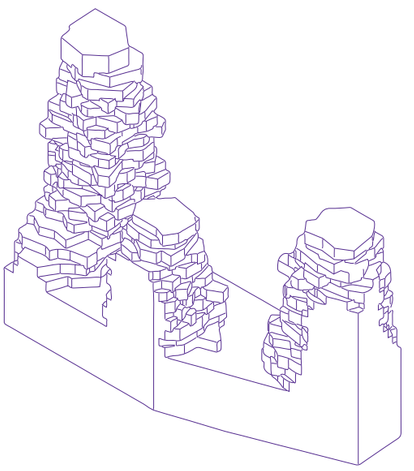




VALLEY

MVRDV

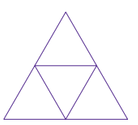
Reference project

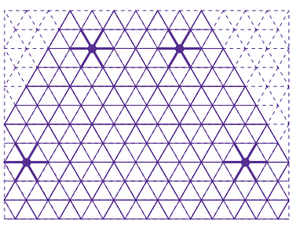


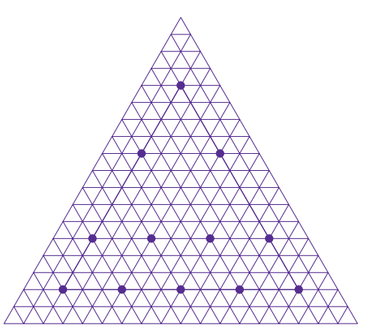
ASSEN STATION

Powerhouse Company & De Zwarte Hond

Reference project



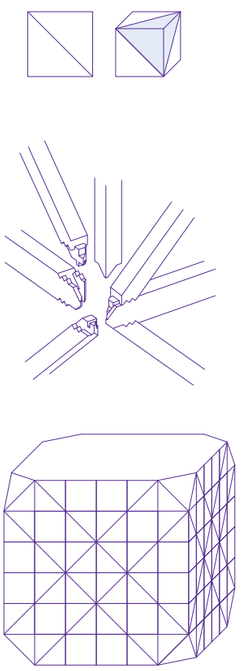




MAKERS' KUBE

Reference project

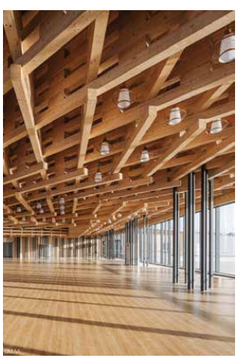
BIG, University of Kansas School of Architecture & Design

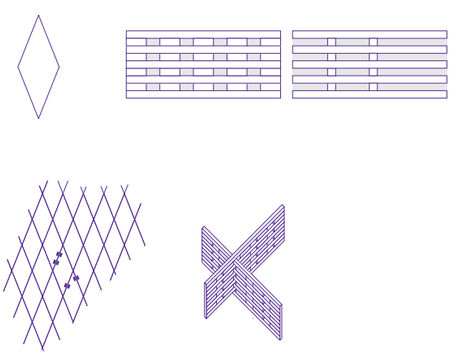


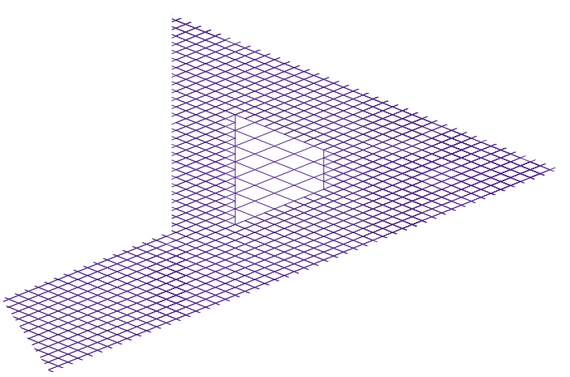
TAIYUAN TEA HOUSE

Reference project

DMAA



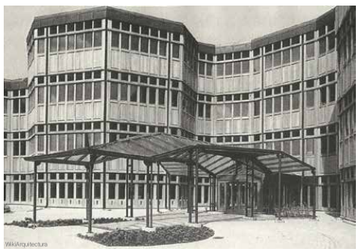


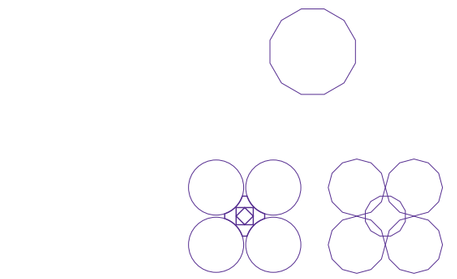


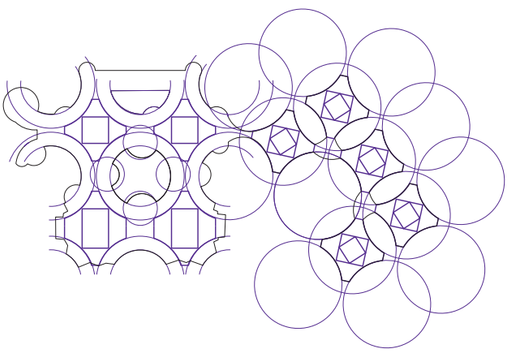
ESTEC BUILDING

Aldo and Hannie van Eyck

Reference project



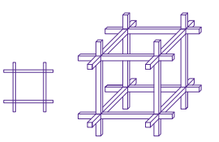


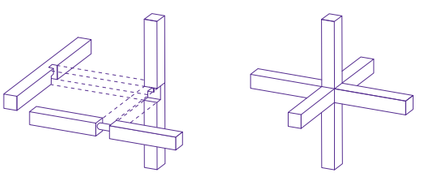


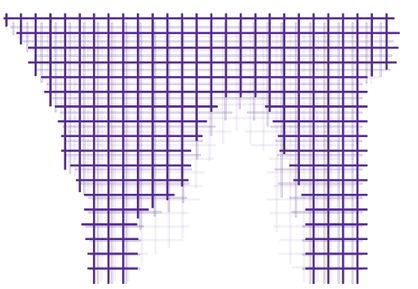
GC PROSTHO MUSEUM RESEARCH CENTER

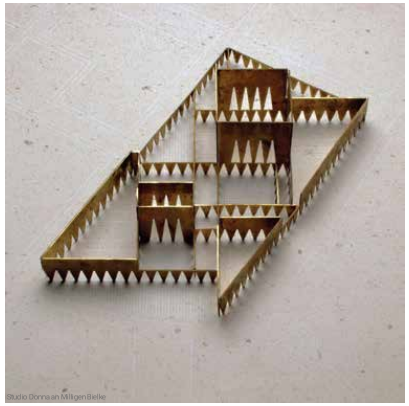
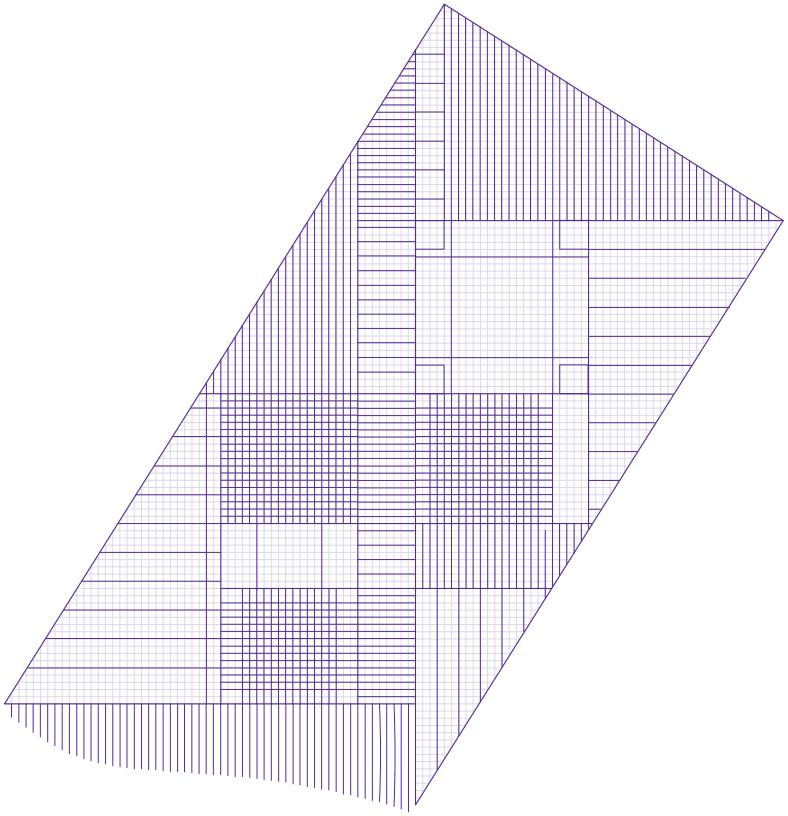
Kengo Kuma

Reference project







ATLAS OF SPACES

Ard de Vries Architects and Studio Donna van Milligen Bielke