THE USE OF SUPPORTS AS THE KEY TO A CIRCULAR FUTURE

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ABSTRACT

The current building industry has to deal with an enormous need for more housing. Besides it has to deal with circularity and changing needs in society. The open building concept has a lot of potential to build in a circular and adaptable way. Open buildings make a distinction between support (permanent part) and infill (flexible part). The support can be built for flexibility and accommodate the circular and adaptable infill. The research focusses on the design of the support and how circular infill building layers can be designed independent from each other. The support is a smart structures which provides maximum flexibility in function, size, program and appearance. All infill building layers have a different lifespan. Therefore they need to be designed for decomposition and disassembly so they can for instance be re-used or recycled.

KEYWORDS: *Open building, Circular Building, Flexible Building, Supports, Architecture*

1. INTRODUCTION

The current building industry has to deal with many challenges nowadays. On the hand is the enormous need for more housing and densification. On the other hand the building industry has to deal with building circular and changing needs in society. These challenges ask for new building strategies worldwide. Many research has been done already about circularity, adaptable buildings and enlarging our cities, but how can the building industry deal with all these issues at ones? The way of building has to change to build circular and for the changing needs of the next generations. In The Netherlands one million homes has to be built before 2030. This paper will address a building guide to build adaptable and circular in a dense urban environment. It is written to inform researchers, architects, builders and designers to learn about the open building concept and how it can be implemented to densify an adaptable and circular neighborhood.

1.1. Problem statement

A circular economy, changing needs in society and the need for more housing are the three problem which will be addressed. These problems are not just local, but form the problems of the building industry worldwide.

The Dutch government has set the goal to become a circular economy in 2050. By this time material depletion, unconscious use of materials and material waste should be the past. (Ministerie van Infrastructuur en Milieu, 2016) The amount of material resources is limited, while the demand on materials is growing. Many material resources are threaten by depletion. Making building components from new materials does not contribute to the energy transition. Many materials are not renewable which means it will be downcycled or treated as waste. Most building are built for 100 years for one specific function. After this period the building needs a lot of maintenance or it is going to be destroyed. Redeveloping a building is in most cases quite radical since most building are not build for change. The vacancy of many office buildings in The Netherlands gives an example of the unpredictable future. Building components with a limited lifespan should be made of reusable/recycled/remanufactured materials. The building parts which have the potential for a long lifespan should be made adaptable for the future so less materials are wasted. (Geldermans, 2018)

Changing needs in society results in vacancy, demolishing and in the end more materials use. The current building stock consist of many inflexible buildings. After their function it is not always possible to give the building a new purpose. Normally a complete transformation is necessary to transform an empty office buildings into a residential building. Different building laws and building techniques makes a transformation complicated and expensive. The only sure thing is that many things will change in future and at this moment no one knows what this change will be.

Cities in the Netherlands have grown rapidly in the last 100 years. Before 2030, the Dutch government wants to build one million homes. To preserve the Dutch countryside, densification is an essential challenge. But, is it possible to build more dense, while still having a high living quality? In many dense neighborhoods residents have a minimum access to green, sun, air and privacy. Nowadays, many homogeneous buildings in many cities result in fruitless, exclusive and vulnerable neighborhoods. Planned urban developments are not always working out, while old city centers in The Netherlands are more resilient and better able to adapt with society.

1.2. Objective

The open building concept has a lot of potential to build in a circular and adaptable way which is both needed towards a sustainable future. Open buildings make a distinction between support and infill. The support represent the most permanent parts of the building like the structure and can be seen as a bookcase. The infill represents the adaptable part of the building or in other words the books. (Habraken, 1961)

A circular building accommodates a circular flow of its building materials and building components. The support of the building accommodates adaptability of the infill components. The program, amount and size of the indoor spaces is adaptable and because of this the support can have an extended lifespan. Infill components are renewable. Each component has a different lifespan. The components and materials of the infill are reused, recycled, repaired, refurbished, remanufactured of biodegradable.

An adaptable building is designed to allow easy reorganisation of the internal space and by this accommodating the changing needs of the society. A smart composition of building elements form the support of the building. Many different typologies fit in the flexible support of the open building. This means not only the floorplan is adaptable, but also facades, roofs, outdoor spaces, and servant elements. The support allows change in program, size and infill building components of all kind. Vacancy should be theoretical impossible, because adaptability can cope with changing needs in society.

Densification is needed to build one million homes The Netherlands. Supports could offer qualities a dense area is missing in many cases. Outdoor space with green, sun and privacy could be a part of the support structure. The support system can function as a vertical neighbourhood. Lifted streets with a broad variety of work, living spaces and retail in a mixture of typologies surrounded by lifted outdoor space. The support neighbourhood is inclusive, flexible, mass customized and dynamic neighbourhood which is sustainable in many different ways. What can an open building and specifically the support offer when financial constructions and building laws change and encourage the open building approach?

1.3.Research question

The goal of this research is to offer a guiding structure and design principles for a support which provide maximum flexibility in function, size, program and appearance. A flexible support enables building layers to act independently which makes it possible to adapt building components/materials in different building layers in a circular way. By this, the structure and the foundation (and possibly other layers depending on their lifespan) can last longer and provides the city a sustainable neighborhood. To accomplish this, the following research question has been formulated: *How can a flexible support be designed for a circular and multifunctional open building?* To give an answer to this question, three sub-questions are formulated. 1) What is the definition of the building layers of an open building? 2) How can a flexible support be designed? 3) How can the support provide easy disassembly of infill building layers? The sub-question will be addressed in the following three chapters.

1.4. Method

The research methods applied in this research are literature studies, plan analysis and research by design. The scheme in figure 1 represents the methods and steps which were taken through the research process. In the first chapter a literature study is conducted give a definition of the supports for circularity. The study focuses on the support and infill theory of John Habraken, the lifespan of building layers defined by Steward Brand and the independence of building layers described by Bernard Leupen. In the second chapter the literature study focuses on the structural aspects and the zoning of supports. To get a grasp on the current state of the open building concept and understand and explore the design solutions which are applied, a case study is conducted on existing open buildings. In this case study nine open buildings will be analyzed by their building layers. The literature study in the last chapter focusses on the disassembly of the support and infill building layers. The research by design is applied to merge, unite and decide on the obtained information. A program of requirements which is obtained by the literature study and case studies, will form the foundation for a search for a circular and adaptable support.

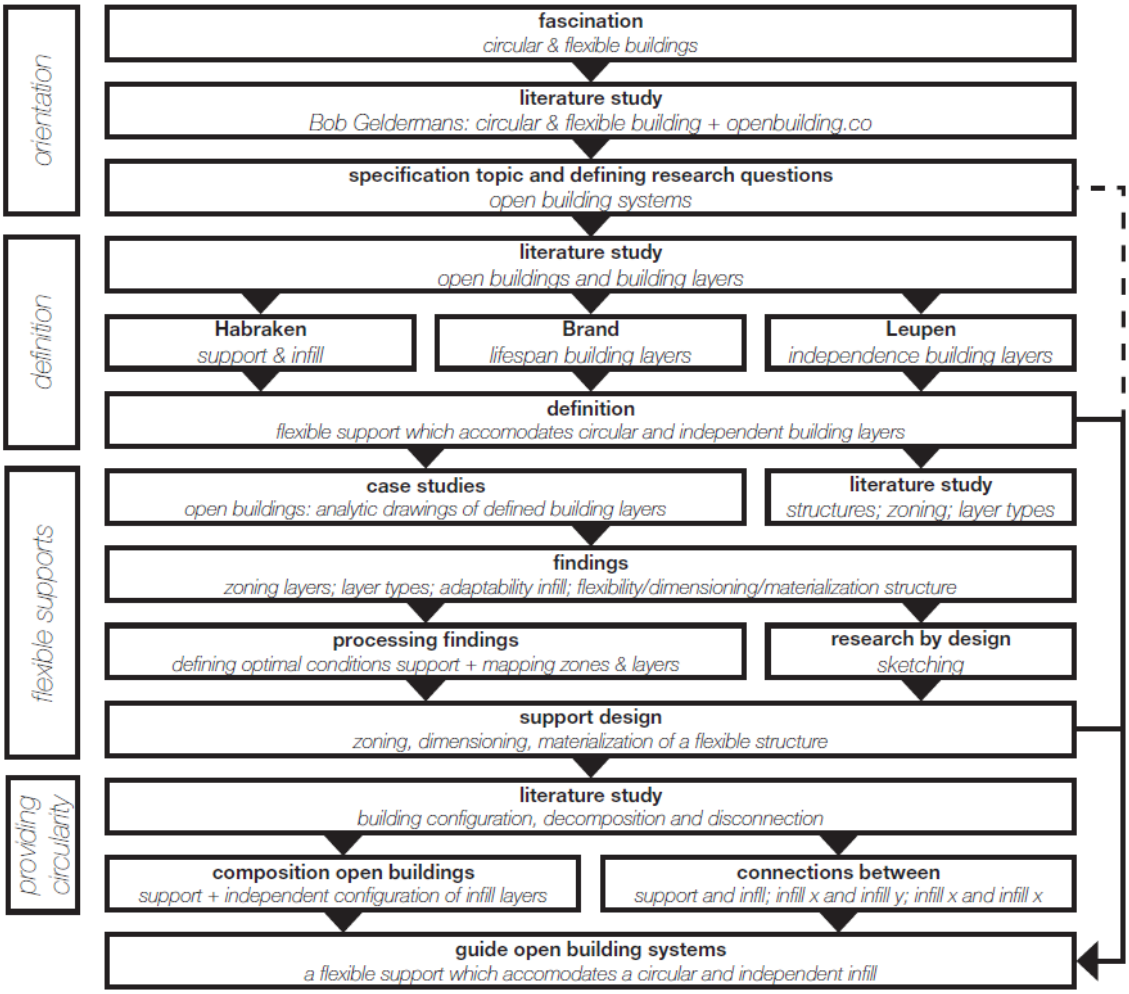

Figure 1 – Method scheme

2. DEFINITION

Open building consist of a support and a infill. But which part of a building is part of the support and which part belongs to the infill. All building components can be divided in several building layers. Each building layer represents its own purpose and is bounded to a certain lifespan. This chapter gives an answer on the definition of building layers in open buildings.

2.1. Open buildings

The open building concept is an approach which takes changes in functions and needs into account. Open buildings can adapt to social and technological change. The concept of open buildings is much more needed in the 21st century to lower the ecological footprint of the building industry, reducing waste, extend the lifetime of buildings, embrace circularity and support the involvement and inclusion of the consumer. (Open Building.co, 2019)

There are three layers within the open building approach: the urban tissue, support and infill. The urban tissue is the design and composition of the outdoor areas like streets, squares, parks, canals and boulevards. The support consist of the permanent framework which form the most permanent elements of a building. Within this fillable framework the infill is the most flexible part of the building (fig. 2). The infill can vary in number, size and function. (Van der Werf, 1993) This research will focus particular on the support

Habraken was the first who advocates the open building concept in order to overcome the problems mass housing is facing. In his book *Supports, an alternative for mass housing*, he argues that lack of user participation, monotony in the built environment and the failure to profit from industrialization is the result of mass-housing construction in the Netherlands. (Habraken, 1961) The concept of support and infill should offer the sollution. The support part represents the collective part and the infill represents the private part. The responsibility of the infill is in the hands of the actual user. To what extend ones agree with the statement on user participation is beyond this paper. However, the distrinction between support and infill makes many things possible and has become more and more relevant as a sollution for circular and adaptable buildings.

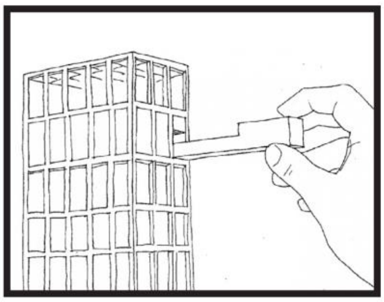

Figure 2 – Principle support and infill

Nowadays, still many open buildings have involved user participation in the design process. However, the call for open buildings is increasing, because it advocates for a more circular and adaptable building environment which has become extremely relevant in the last decades. Geldermans (2018) describes the connection between flexible buildings and circular buildings principles. The currently built circular buildings make a distinction between structural and non-structural elements. This allows a circular material flow, while at the same time using the same principles as flexible buildings. Flexible buildings accommodate change by separate structural and non-structural elements which allows changing spatial configurations to respond to the changing needs and requirements of the occupants. Therefore, the open building concept embraces both circular and flexible principles. Mass customized and industrial manufactured infill components can be designed and installed in a circular way when a smart supports allows adaptability in many different ways like program, size, function and different technical needs and requirements.

In his article Circular & flexible building, Geldermans (2018) defines a circular building *(verb)* as: ''*the dynamic total of associated processes, materials and stakeholders that accommodate circular flows of building materials and products at optimal rates and utilities. A circular building (noun) is the manifestation of this in a temporary configuration.''* This definition raises the question which building materials and products are part of the circular flow. In other words, which building-components or building-layers are part of the support and which are part of the flexible infill. This will be discussed in the next paragraph. What is already clear is that the support is the most permanent part of the building. The support accommodates the circular flow. This means that a support depends on its transformation capacity. This is an essential factor for circular buildings because a high transformation capacity results in building components which can be disassembled and reassembled easy so they can be re-used, recycled, repaired, remanufactured or refurbished (renewability capacity). (Durmisevic, 2006; Geldermans, 2018) Figure 3 shows the buildings layers defined by Steward Brand. The building layers are related to their lifespan. The structure represents 30-300 years, the skin 30-50 years, the services 7-20 years and the space plan 5-7 years. A lifespan which is as long as possible is the most optimal situation from a sustainability point of view.

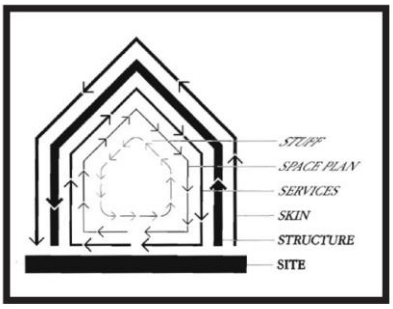

Figure 3 – building layers related to the time (Brand, 1994)

Also this figure shows that the structure will be the most important and permanent part of the support. Nonetheless, this raises the question to what extend the structure should be circular itself. The structure and the foundation is most of the time built up from mineral materials. In combination with the relatively large quantities of these materials like concrete, the structure is responsible for a relatively large amount of the embodied energy of a building. The embodied energy is the energy which is necessary to produce a product in all its processes like mining, transportation and manufacturing. (Hildebrand, 2014) The structure was part of the permanent in all the flexible experiments analyzed by Leupen (2002). The most ideal is that the structure can last for its maximum lifespan of 300 years.

In his article Circular & flexible building, Geldermans (2018, p. 60) defines a flexible building as: ''*a building (noun) or building activity (verb) designed to allow easy rearrangement of the internal fit-out, whilst accommodating the potentially changing needs of occupants.''* Because a flexible buildings can accommodate change, it can have a much longer life span than a building which is built for one specific function. Reinier de Graaf of OMA explained that a building should be used for what it was not intended to be use for. (Oscar Properties, 2018) The built environment is not a static product, but a dynamic phenomenon which is changing constantly. The viability of a city is in its ability to change, but nevertheless keeping its identity. Supports offer the built environment the possibility to respond to the actual needs and requirements at a specific time for a specific user while mass housing offers one static design for unknown future occupants. (Van der Werf, 1993; Habraken, 1961) Geldermans (2018) describes two conclusions which can be drawn by observing the trends and history of the built envirment. First, the housing requirement differ per person, group and time. Second, houses are almost always designed with one specific occupant in mind which result in inflexible housing. Alterations in housing may differ from changing in family size, new access requirements, building regulations and other tendencies and lifestyle changes. Leupen (2002) describes three types of changeability: alterable, extendable and polyvalent. Alterability represents change of internal modifications like moving a wall or a adding a door. Extendability is change in the size of the space like an expansion forwards, sideways or upwards. Polyvalence represents the change of the internal arrangment without architectural or structural alterations. A support should accommodates these three changes. Besides the transformation capacity, which is already described, the flexibility capacity also depends on disassembly, reassembly, repurposing and disposing of building components. (Geldermans, 2018) When non-structural elements can be removed, added or moved easily, a building can really adopt to the needs and requirements of future occupants. Smart flexible buildings can have a longer lifespan. The most flexible building can not only change in size, but also in function. The solution for this is to design a support for housing and commercial both. There are many examples where a commercial building is transformed to housing. If there is no difference in building laws for the support of different functions, it can result in flexible and adaptable buildings. Practically, this means that the loadbearing capacity, floor heights, physical characteristics like sound insulation, fire safety, energy and installation technology should not be an obstruction. (Platform CB'23, 2020) Steward Brand (1994) states that age and adaptivity is what people makes to love a building. All buildings change during their lifespan, however only a few of them improve.

2.2. Building layers

Frank Duffy (1990, p. 17) states that: *''there isn't such a thing as a building. A building properly conceived is several layers of longevity of built components.''* Buildings are compositions of different building elements like floors, columns, windows, pipes, lifts and so on. The building layers defined by Steward brand are already shown in the 2.1. Also Leupen (2002) comes with a classification of building layers. In figure 4 the classification of building layers is shown.

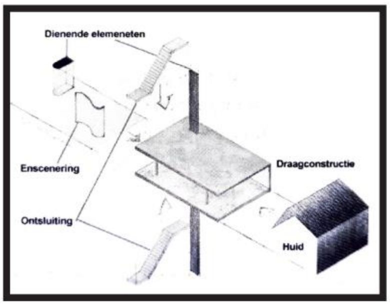

Figure 4 – Building layers by Leupen (Leupen, 2002)

Leupen defines the layers structure, skin, access elements, servant elements and scenery. This classification is almost the same as the classification of Brand. Leupen has added the layer access elements in his classification, because of the many extensive access elements in contemporary buildings. What exactly belongs to each layer depends on the function of a group of building elements. Basically the structure represents the elements which are responsible for transferring the bearing loads to the foundation (columns/beams/walls/trusses/floors). The skin separates the inside from the outside (cladding of the façade and the roof). Access elements take care of the accessibility of the units (stairs/corridors/galleries/lifts). Servant elements provide the building of energy, water, data, air, warm and cold (pipes/cables/appliances. The scenery is mostly connected to the layout of the space (partition walls/doors/finishing's) (Leupen, 2002).

High quality outdoor space have become more important in our growing cities. Densification and outdoor space seem to be two opponents. However, in the last decade there is a growing trend of increasing high quality outdoor spaces in dense areas. More and more mid- and high rise buildings with high quality outdoor spaces are realized like Bosco Verticale and Singapore's Tree House.

The support can extend the outdoor space in a neighborhood. It gives the building the opportunity to accommodate greenery which will contribute to a healthier city. Greenery can lower the urban heat island effect and the air pollution. Besides it can compensate CO2 emissions, enlarging biodiversity, absorb rainwater and promote social cohesion. The outdoor space within supports can function as elevated streets and be designed for more flexible, green, social and accessible spaces. In his first book, Habraken described the roof of the supports as public gardens. (Habraken, 1961) Later, he makes with the SAR (1973) a distinction between outdoor in-between spaces: O-spaces, which are public, and P-spaces, which form the in-between space which is only accessible by (collective) private users. Besides, a subdivision makes a distinction between α-spaces, which represents spaces that have a relation with the interior and β-spaces, which doesn't have a relation with the interior. With the division four combinations can be created: αO, βO, αP and βP.

Steward Brand (1994) emphasizes that allowing slippage between building layers is essential to make an adaptable building. In an adaptable building, a slow system, like the structure, will not block the flow of a quick layer, like services. Besides, a quick layer may wreck slow layers due to their constant change. Embedding layers could be efficient in the first place, but on the long term it will be destructive. Also Leupen highlights that a high independency of building layers will make building adaptable. By disconnecting a layer of a building the building layer becomes independent. This means that the disconnected layer has no function anymore for another building layer. After disconnecting it is possible to separated layers physical. For instance, when the structure carries the entire load, a partition wall can be disconnected and move freely. In other words, after disconnecting the adaptable infill it is free from the support. From this perspective we can look back at the statement of Duffy that a building is a composition of layers with its own development, lifespan and articulation. The disconnection between layers should be physical simple. The excision represents the border along the disconnecting layers. The excision can contain many forms like a minimal suspension frame, screwable connections or dowels. The excision is minimum when building layers are designed for disassembly and re-assembly.

2.3. Support and infill

The role of open buildings, the independency of building layers and their relation with circularity and adaptability became clear in the previous paragraphs. This raises the question how the independency of building layers fit within the open building concept. Which layers are represented by the support and which one belong to the infill? In other words, what is a support which accommodates circularity and adaptability considering the theories of Habraken, Brand and Leupen? (fig. 5)

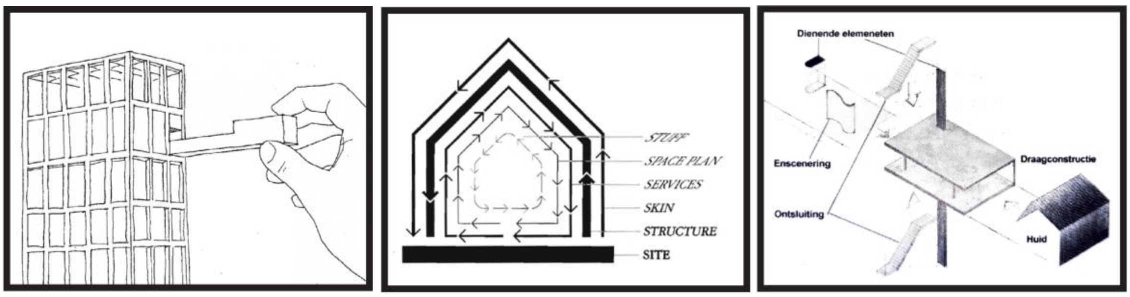

Figure 5 – Habraken (support and infill), Brand (lifespan of layers) and Leupen (frame and generic space)

Leupen describes the frame which represents the most permanent part of the building. The frame creates conditions for change and is autonomous and independent from its content. The space defined by the frame is the generic space. Change can take place within the generic space. (Leupen, 2002) In the theory of Habraken, the support forms a frame which accommodates change. We could call the space defined by the support the generic space as well. Within this generic space, independent building layers form the circular infill of the open building. A smart structure forms the support which offers the greatest variety and allows for a number of different layouts for different functions. (Habraken, 1976) Habraken describes in his first book the support as not just a structural skeleton. He mentions that the support is a self-completed thing and not only a smart structure but a building on its own. (Habraken, 1961) The support (or smart structure) forms the frame for the building. However, the frame can also include other building layers when the building is transformed or renewed. In this situation the frame is formed by the structure and for instance the skin and access layers. Also a part of a building layer can belong to the frame like the vertical servant elements. Many times the frame will consist of the structure, vertical access and servant elements, outdoor spaces and the skin. Scenery and horizontal services will probably be the most changeable layers. In conclusion, the support is a smart structure and forms the frame which can also consist of other layers depending on the transformation.

The program of gross floor area is less relevant since the amount of units can increase and decrease due to the flexible support. (Van der Werf , 1993) Habraken emphasizes that the support should have the same section as much as possible. Vertical connections should preferably be located outside the support. This means that elevators and stairs should be located outside the structure as much as possible. (Habraken, 2001) The support accommodates the flexible positions of the vertical transport layers. By creating broadly defined zones for layers and space types the supports will get its form. Zones have a specific dimensions based on a broad variety of future functions. The support structure must meet all requirements for both housing, workspaces and public buildings. To a certain extend it is able to accommodate building layers with different structural requirements. By this, architects can create real value on a long term by using a frame which accommodate circularity. The support does not have to be demolished, but keeps its value for other users. (Platform CB'23, 2020) Therefore it should be designed for maximum safety, durability, performance, capacity, flexibility and adaptability. (Kendall & Teicher, 2002)

The generic space which is defined by the support allows a flexible and circular infill. The infill has to change many times throughout the life cycle of the support. Interference and conflict between layers should be avoided and parties controlling them. (Kendall & Teicher, 2002) The layers skin, access elements, servant elements, scenery and outdoor space form together the infill. This doesn’t mean each layer will change a lot of times. Some layers, like the skin, might even last for hundred or more years when the façade is still able to accommodate the function. People can appreciate the building for its appearance and give a lot of value to for instance its skin. In this situation the skin will be part of the frame for a long time. Specially in western countries, the façade is mostly a uniform common property and is a part of the collective design. (Kendall & Teicher, 2002) The infill is part of the architecture and can be bound to the rules of the building when something changes. The independency of building layers makes it easier to implement user participation in the design process. Too what extend this is implemented is the decision of the architect or the contractor. This can be limited to vertical elements in the scenery layer like partition walls, but it could also include the skin like individual customized façade elements. Independent layers make it easier to make for instance a limited catalog of dwelling layouts or a personality kit. Here dwellers can choose from several building elements, like door types, window frames or shutters. Infill specialists can appear on the market. (Habraken, 2001) But basically the architect can design everything and isn’t bound to the support. In fact, the support or structure may be given by for instance the contractor, while the architect is responsible for the infill. Summarized, the use of support and infill can lead to many different implementations in the design process. However, the most important aspect is that the infill is flexible and circular which means it is designed for disassembly.

Dividing a building in layers can be confusing. For instance, a façade or a staircase could also consist of a structure. However, since all layers should be designed independently, this structure has no other function than a structural function for its specific layer. This means that the structural elements of a staircase belong to the access layer. In this case the structural elements of the staircase are a sublayer of the access layer. (Leupen, 2002)

Nine case studies are conducted to get a better understanding of supports and infill of open buildings. The building layers structure, skin, access elements, servant elements, scenery and outdoor space are analyzed of each open building which are presented in appendix 1. In the analysis special attention is on the type of structure, the dimensioning of the structure, the facade type and its flexibility, the locations of the vertical servant and access elements, the flexibility of the scenery and the type and function of the outdoor space. The buildings are built between and 1974 and 2020. The analysis includes Patch22 by Frantzen, Object One by Space and Matter, CiWiCo by GAAGA, Stories by Olaf Gipser, Superlofts by Koehler, Next 21 by Utida, Molenvliet by Van der Werf, Maison Mediacle by Kroll and Hoge Vrijheid by Van der Hijden. (fig. 6)

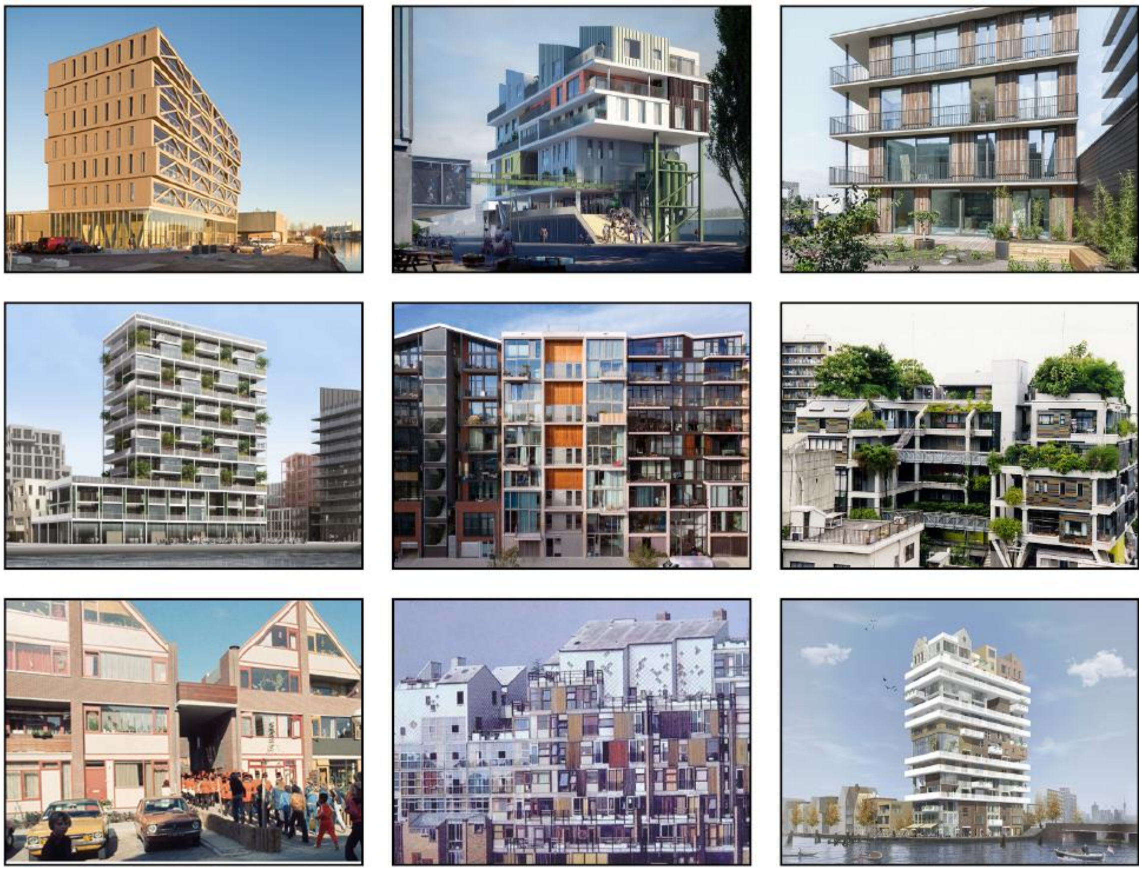

Figure 6 – Analyzed open buildings (first row: Patch22 by Frantzen, Object One by Space and Matter and CiWiCo by GAAGA; second row: Stories by Olaf Gipser, Superlofts by Koehler and Next 21 by Utida; third row: Molenvliet by Van der Werf, Maison Mediacle by Kroll and Hoge Vrijheid by Van der Hijden.

3. FLEXIBLE SUPPORTS

The support is a smart structure which accommodates the circular infill layers. Together they can form a frame for the change of one or more specific layers. In this chapter, the design of the support will be addressed. The structure type, zoning of spaces and layers and the dimensions of the support will be discussed.

3.1. Structures

What kind of structures are suitable for a flexible and circular open building? Engel (1997) describes all kind of structures that can be applied in the building environment. In general there are four types of structures which can be applied in a building: bay-types, casing types, core types and bridge types. This study will focus on a support height between around 10 and 50 meters, because this is manageable height to adjust a building and can offer livability and density at the same time. The case studies in appendix 1 show that only bay structures are applied in open buildings.

Bay structures can be divided into four types: framed bays, trussed bays, stabilized post-beam bays and shear walls. In the open buildings either shear walls or stabilized post-beam bays in the form of core stabilization are applied. The only exception is Next 21 by Yositika Utida where framed bays of a robust concrete skeleton and rigid connection form the structure of the building. The structure offers a lot of flexibility in width and in height. Elevated streets on the inside of the block are built within the structural system. The flexibility of open building with shear walls is quite different. In particular the structure of CiWoCo and Maison Médicale offer a lot of flexibility. CiWoCo has bearing walls in the façade which makes the interior very flexible, but it also determines the position of the façade openings. Molenvliet also offers a flexible structure, but it creates more conditions for the floor arrangement. It makes the support is less generalistic and it gives the building already character. At the same time it has an unformal section which is described by Habraken as a valuable condition for supports. (Habraken, 2001) Also open building with core stabilization offer a lot of flexibility in the layout of the building. Patch 22 has a central core in which the vertical access- and servant elements are situated. This is the case in most building with a central core. However, the vertical access- and servant elements could be more dependent on the structure in this case. It is important that access and servant elements can be disassembled without interference of the structural core.

Most open building structures are made of reinforced concrete. The structure of Patch22 and Stories are made of a combination of reinforced concrete and crossed-laminated timber (CLT). In Patch22 the central core, the first floor and the floorplates on the upper floors are made of concrete. The structural columns and beams on the upper floors are made of CLT. In Stories only the central core and the first floor is made of concrete. The floors and the walls with large cut-outs of the upper floors are both made of CLT. The applied materials in the upper floors has consequences for the span length of the columns. In Patch22 (with the concrete floors) this is 9 meters while in Stories (with the CLT floors) the span width is just 4,5 meters. A building with a larger floor span is in general more flexible. A accurate chosen span requires a scenario study on the possible functions and floor layouts.

Since the outdoor space is defined as a building layers in this research, the structural system should be able to adapt to this layer. Could the outdoor space be removed without interference of the structure? In many high rise buildings with outdoor space the structure is inseparable with the balconies or terraces. Four structure of building (which are also all bay-type structures) with a lot of outdoor space are analyzed in Appendix 2. In the project Nice Merídia by Nicolas Laisné Architects the outdoor space has a separate structure. This means the outdoor spaces can be removed from the ordinary structural system without demolishing the whole building. This is also applied in Stories by Olaf Gipser. (Appendix 1) The balconies are built of a separate steel structure which is attached to the building. (See fig. 7) This makes the outdoor space less dependent on the ordinary structure. The balconies of Superlofts by Koehler are attached to the ordinary concrete structure, but can they can be disassembled without interference.

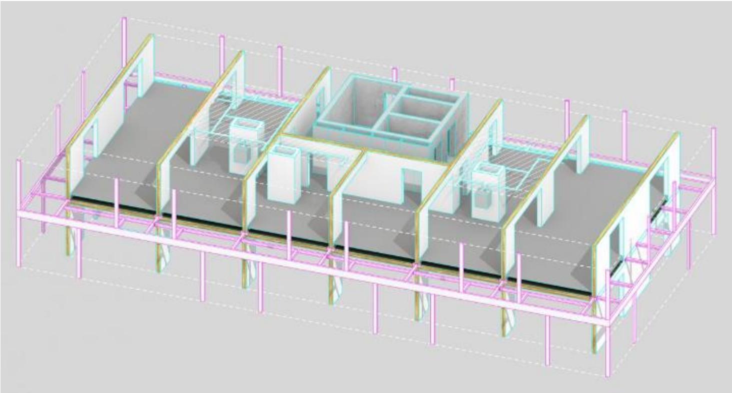

Figure 7 – Stories has a separate steel structure for the balconies (Gipser, 2020)

A structure with shear wall or core stabilization seems to be the most suitable structure types for open building. Depending on the most ideal span (which will be discussed in paragraph 3.3) the structural materials can be chosen. The structure of other layers like the outdoor space should be separated form the ordinary structure. The structural functions will assign the most efficient and sustainable materials for its specific purpose per building layers. A hybrid structural building of separable structural layers will be the most efficient.

3.2. Zoning and layer types

The layout of the support is depending on the zoning and the types of other layers. Specially the place of the access elements and the vertical service elements have a lot of impact on the support. The location and dimensions of detachable layer components must clearly defined. (Habraken, 1976) In Appendix 3 is shown the zoning of the access elements, service elements and the outdoor space relative to the support. The position of these three layers has the most impact on the structural layout.

Habraken (1976) defined several zones within the support. (fig. 8) The α-zone is inside and adjacent to an external wall. The β-zone is inside as well, but not adjacent to an external wall. It is situated between two α-zones. The δ-zone is private outdoor space and the most outer zone. The γ-zone is intended for public use and can be both internal or external. Between each zone is a margin.

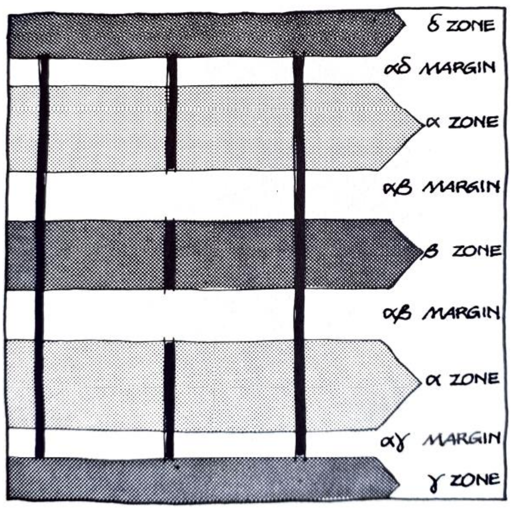

Figure 8 – Zoning supports defined by Habraken (Habraken, 1976)

Van der Werf (1993) describes three space types: the parcelable space (α-zones - and β-zone), the access space (γ-zone) and the private outdoor space (δ-zone). The parcelable space will be divided in units for housing, workspaces, shop and so on. All kind of structural elements like walls, columns or arches can be used. The generic space can be orientated in the longitudinal- or cross direction. Light and air supply can be utilized when the walls are placed perpendicular on the facade instead of in a longitudinal direction. By doing this, the depth of the support can be increased. Dividing of units can be more nuanced when placing bearing walls along the façade. Both orientation strategies can be combined which can be seen in Molenvliet (Appendix A). Units can also be divided vertically. Openings in the floor are needed when units are also divided in a vertical direction. The undivided support looks like an open an semi-transparent structure. The access spaces like staircases, lifts and corridors are all collective spaces which can be both insides or outside. The maximum amount of units per floor depends on the amount of possible entrances. Dwellings should have at least two vertical escaping routes which should be included in the design. There are six types of private outdoor space: balconies, loggia's, gardens, terraces, roof terraces and patio's. Each units should be able to have its own private outdoor space. Also after splitting units, the outdoor space should still be available for both units. The flexibility is guaranteed when for instance balconies continue along the facade. All three space types have to be design together. The most flexible interplay between the spaces and layers will result in the circular support. (Van der Werf, 1993)

Within each layer are many different types. The structure can consist of columns or walls and the access elements can consist of corridors or galleries. In Appendix 4 different types of components of the six building layers are presented which could be relevant in the open building. The layers are divided in horizontal and vertical to make the analysis more accurate.

To define the most efficient position of building layers and components of the layer types will be evaluated. Based on the discussed theory, the most optimal conditions are defined for the vertical and horizontal types of each layer (see table 1).

Table 1. Building layer optimal conditions.

building layer	**orientation**	**optimal conditions**
Structure	vertical	1. The structure is flexible and open for multiple types of layouts 2. The structure has spacious qualities; columns tend to be more neutral and have less spacious meaning
	horizontal	1. The structure is flexible and open for vertical arrangements of one or multiple units 2. The structure has a high thermal heat capacity which will make the building more energy efficient
Skin	vertical	1. Openings in the skin can be changed due to its flexibility 2. The interference with outdoor spaces is minimalized
	horizontal	1. The skin provides an optimal use of space 2. The horizontal elements of the skin can provide an extension of the outdoor space
Access elements	vertical	1. The vertical access is independent from the structure 2. The distance from a unit to a vertical access element is small

	horizontal	1. Additional entrances can be added later due to flexible horizontal access spaces 2. The access spaces have a potential social character
Servant elements	vertical	1. The location of the wet-cells is flexible 2. The space of the vertical servant elements is space efficient
	horizontal	1. The location of wet cells is easy adaptable 2. The place of the horizontal servant elements is space efficient
Scenery	vertical	1. The floorplan of each level is flexible with minimal interference of other layers 2. A structural system gives form to the internal layout
	horizontal	1. The layout is flexible in section due to a generous free height 2. Sound insulation between level is as much as possible integrated in the permanent structure
Outdoor space	vertical	1. Outdoor spaces can be divided in smaller outdoor spaces 2. Outdoor space are space efficient
	horizontal	1. The outdoor space is adaptable 2. Each unit has as much outdoor space as possible

In appendix 4 the different types of building layer are analyzed by using the defined optimal conditions in table 1. The most optimal types and the zoning of building layers is shown in figure 9. The optimal structure consist of a skeleton of slab-columns in the vertical direction and a combination of a monolith and skeleton floor for optimal flexibility and at the same time a high thermal capacity. The skeleton floor can be located in the β-zone so units on different floors can be combined. The skin consist of a membrane-like façade (grid) which can offer flexibility in façade openings. A flat roof is the most space efficient and can also be used for outdoor space. The vertical access is separated from the building to minimalize the interference with other layer like the structure. An (elevated) streets brings the users to the units. The elevated street along the façade is able to accommodates flexible entrances which can be added or removed. Besides, the streets has the potential to become a social space instead of a access space only. Vertical servant elements should be placed in service zones which should be located at strategic positions in the building. The location of the wet-cells should be flexible while the spatial influence of shafts should be minimalized. The location of the wet-cells can be completely flexible when using a hollow floor for horizontal transportation. The support provides a space which is adaptable in many ways for all kind of purposes. Partitions walls, doors and finishing's can be installed according to the needs of the user. Partition walls between units should have a proper sound insulation and they have to meet the fire safety regulations. Attached balconies are the most efficient to create outdoor space at each level of the building. The roof can be used as well for a collective or public function.

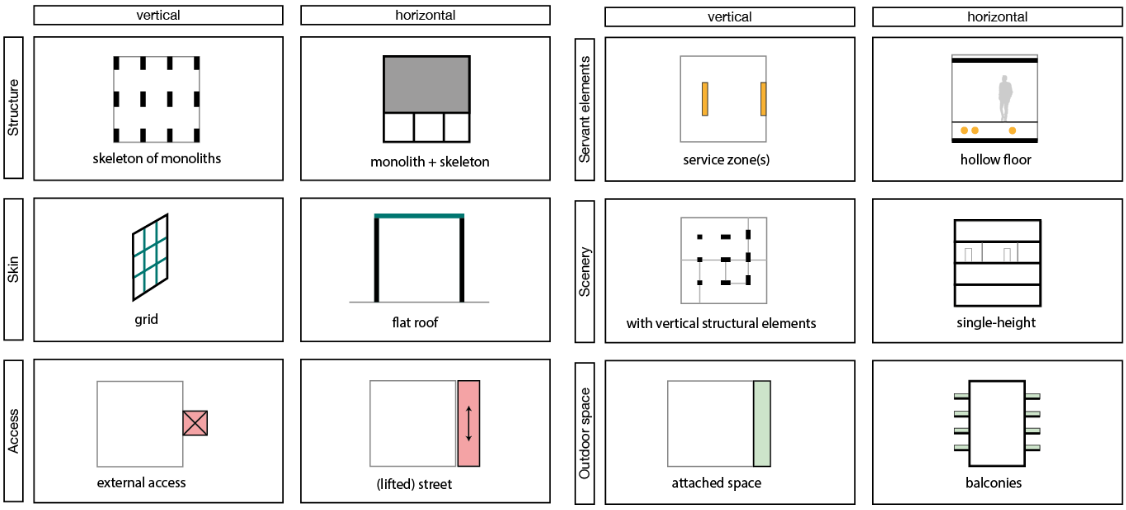

Figure 9 – Optimal types and zoning building layers

The optimal support zoning can be defined by using the zoning scheme of Habraken in figure 8 and the defined optimal types of the zoning building layers in figure 9. In figure 10 the studied zoning principles are combined into one generic floorplan and section. It shows the α-zones, β-zone, γ-zone and the δ-zone and at the same time the defined typological building layers for a flexible support which accommodates circularity of the building layers. The α-zones and the β-zones are internal zones for private use. The β-zone, which is located in the middle of the structure, consist of a vide on every second floor (fig. 11). This makes it possible to place stairs in the center part of the structure and combine two different floors. All layers should be able to contain many different forms. The γ-zone which represents the access side of the support could for instance consist of lifted streets between every two floors but also one or multiple elevators which are connected directly to multiple entrances in the α-zone.

Figure 10 – Optimal zoning based on zoning principles of Habraken and optimal building layer types

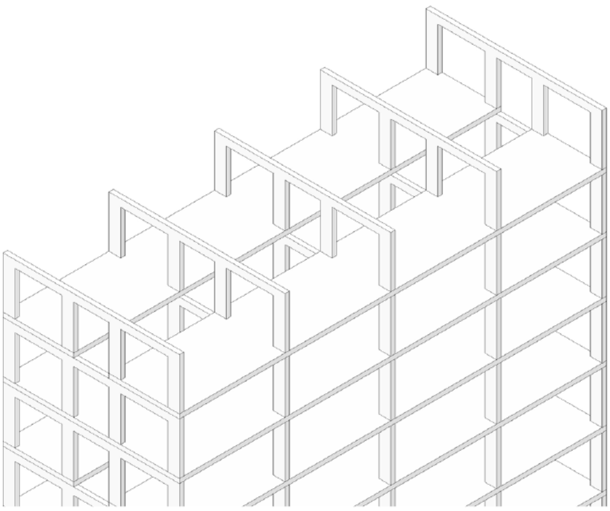
Figure 11 – Support structure

3.3. Dimensions

The support should be able to accommodate many different layouts for different functions. A smart structural plan with carefully chosen dimensions is the foundation for a divers set of floorplans. A program scenario and material properties define the dimensions of the support which is based on the building layer types which are discussed in the previous paragraph.

As described earlier, the support is able to accommodate different kind of dwellings, workspaces, retail and so on. The bay dimensions depends on the materialization of the structure. Different dimensions are applied in the case studies in appendix 1. Patch22 has a bay with of 9 meter and Stories has a bay width of 4,5 meter. Stories has CLT floors which explains the applied smaller floor span. For the dimensions on the support it is sufficient to choose logical dimensions which are commonly used in the building industry. At the same time it should be space efficient and offer flexibility in program and functions. Larger bays can offer more flexibility than smaller bays and they are more flexible as well. Besides, a longer façade length with respect to the floor area is more efficient for the users so more spaces can placed adjacent to the façade and profit from natural daylight and views. (Van der Werf, 1993) A slab building has more façade length than a square block. The dimensions are depending on the direction of the structural elements.

A common used dimension is a multiple of 2400mm for the bays. In Next 21 the bay dimensions are 7200mm which is a multiple of 2400mm. Bays of 7200mm offer many possibilities. Basically, it is possible to make three small rooms of 2400mm, two larger rooms of 3600mm or one large room with a width of 7200mm. But of course there are many other combination possible like a large room of 4800 mm and a smaller room of 2400mm. Within a flexible structure it is possible to make one space on one floor, but the bay width determines the smallest possible unit which is the most interesting aspect in a flexible structure.

In most building it is hard to change the building function due to the different regulations. In Patch22 (appendix 1) the floor height is 3,5 meter. Within this 3,5 meter space a hollow floors is installed to accommodate horizontal servant transportation. A support with a 3,5 meter floor height can accommodate both housing, dwellings and retail. The project Next 21 has a gross floor height of 3,6 meter. The gross floor height can be 2400 multiplied by one and a half which is 3600mm.

The depth of the bays depends on the zoning of the building. In the previous paragraph Habraken defined several zones within the support. The internal zones are the α-zone and the β-zone. A multiply of 2400 can also be applied in the depth of the zones. The α-zone will be 4800mm and the β-zone will be 2400mm (fig. 12). This means the total depth of the support is 12000mm. When the β-zone is not used for wet-cells and the entire floor of support forms one unit without any partition wall, it is still possible to get enough daylight in the center of the building. When for instance the floor construction is 300mm and a hollow floors for the horizontal service transport is also 300mm the net floor height is 3600 - 300 - 300 = 3000mm. The rule of thumb defines the daylighting twice the size of the window height. (Yanovshtschinsky, Huijbers, & Van den Dobbelsteen, 2013) When the net floor height is 3000mm, the daylight can penetrate six meter into the building. When the façade on both sides offer optimal window heights, this allows enough daylight everywhere in the support. A depth of 2400 of the β-zone is a proper dimension for wet-cells like a bathroom.

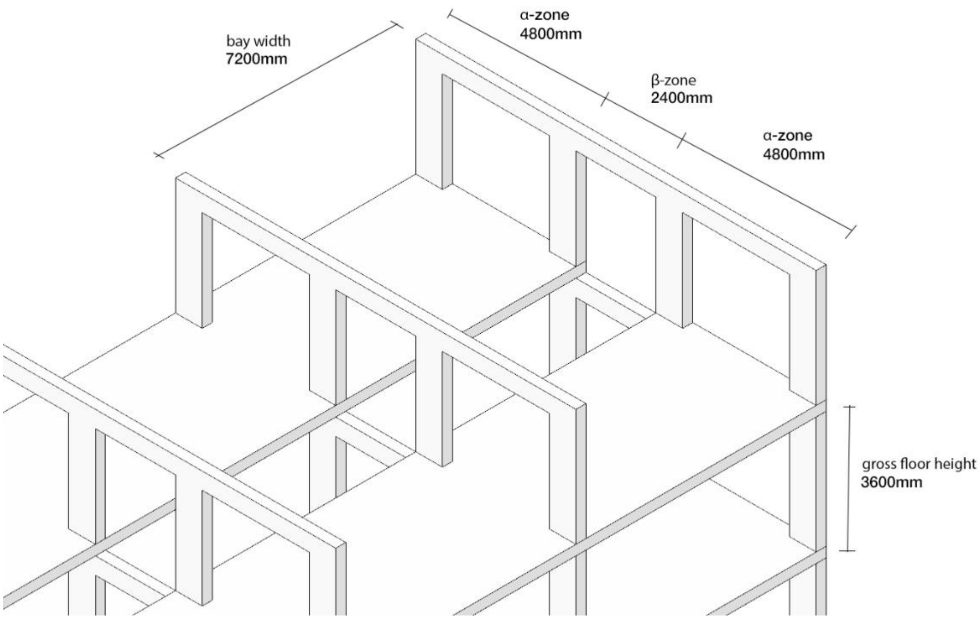

Figure 12 – Dimensions support

The bay dimensions are also depending on the structural material. In the open building analyzed in appendix 1, concrete and crossed-laminated timber are used for the structure. Concrete has a larger span length than wood and at the same time a higher thermal capacity. CLT is more sustainable to produce compared to concrete. In Patch 22 a combination of CLT portals and concrete floors result in a flexible structure. Concrete floors in combination with CLT portals can span more than 7200mm. Both material qualities like the structural strength and thermal capacity for concrete and the structural strength and sustainable qualities of CLT are used and make this combination of materials the most suitable for the support.

4. Providing circularity

The support accommodates the circular flow. A high transformation capacity of the support depends on the possibility of disassembly and reassembly of building layers and their components. Infill layers can be replaced, re-used, recycled or repurposed after their function or technical life span. The disconnection between layers should be physical simple. Besides, the interference between layers should be avoided so the layer can be disassembled without disturbing another layer. This chapter will address assembly and disassembly methods between the support and the infill building layers.

4.1. Decomposition

Design for disassembly is feasible when there is a separation of functions between building layers. A building system or component can only be independent if it has no other functions other than its specific function within its own layer or system. When more than one function is integrated in a layer or system, a small transformation could have a huge and unnecessary impact on other layers to fulfill a new user requirement. The last section in figure 13 shows independent components of a wall which all have a separated functions. When one of the components is replaced, it does not affect the other components. (Durmisevic, 2006)

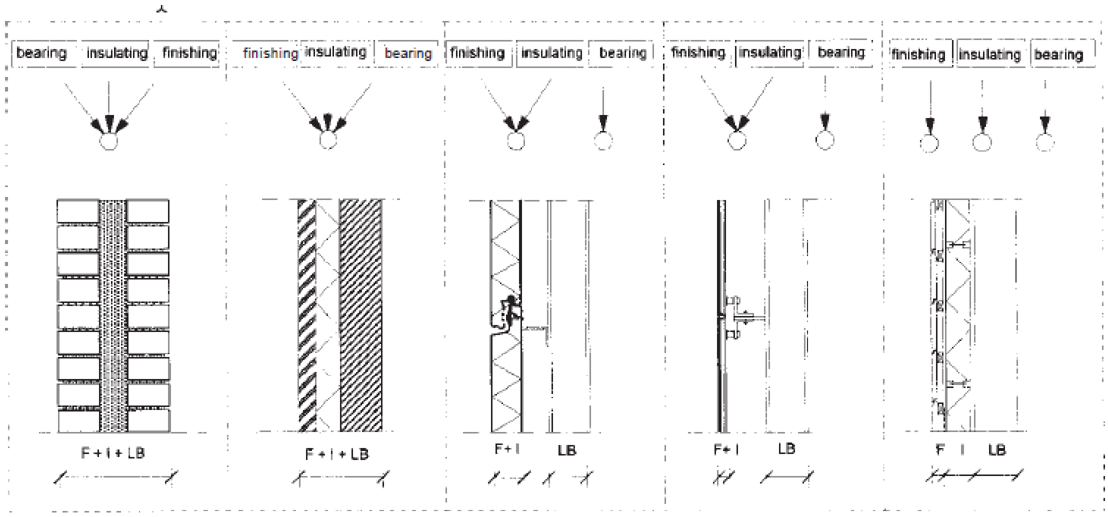

Figure 13 – integration of functions within an exterior wall system (Durmisevic, 2006, p. 164)

The replacement process can occur on the site or in the factory. Layers and systems will be replaced mostly on the site, while replacement of components or materials will be taken place in a factory. When a large number of components is integrated in one system, fewer physical connections are necessary on the site. By this, a quick transformation of the open building is possible. (Durmisevic, 2006)

The building sequence of the layers or systems can be an obstacle when changing a specific part of a layer or system. When many disassembly actions has to be taken, one might even choose to take down a complete building layer for just a small adjustment. A systematization of building layers, systems, components and materials makes it possible to disassembly a specific system. Clusters of layers, systems and components are related to their functions. A system should not have a direct connection with another system. The sequential order, hierarchy and any relation with other clusters is determined by the use and technical life cycle of the elements in the cluster. The systematization of a building configuration is shown in figure 14. The life cycle, functional coordination, assembly and disassembly are easier when more elements are systematized into independent assemblies. Clusters of layers, systems, components and materials at which each part only depends on one entity in the parent cluster. (Durmisevic, 2006)

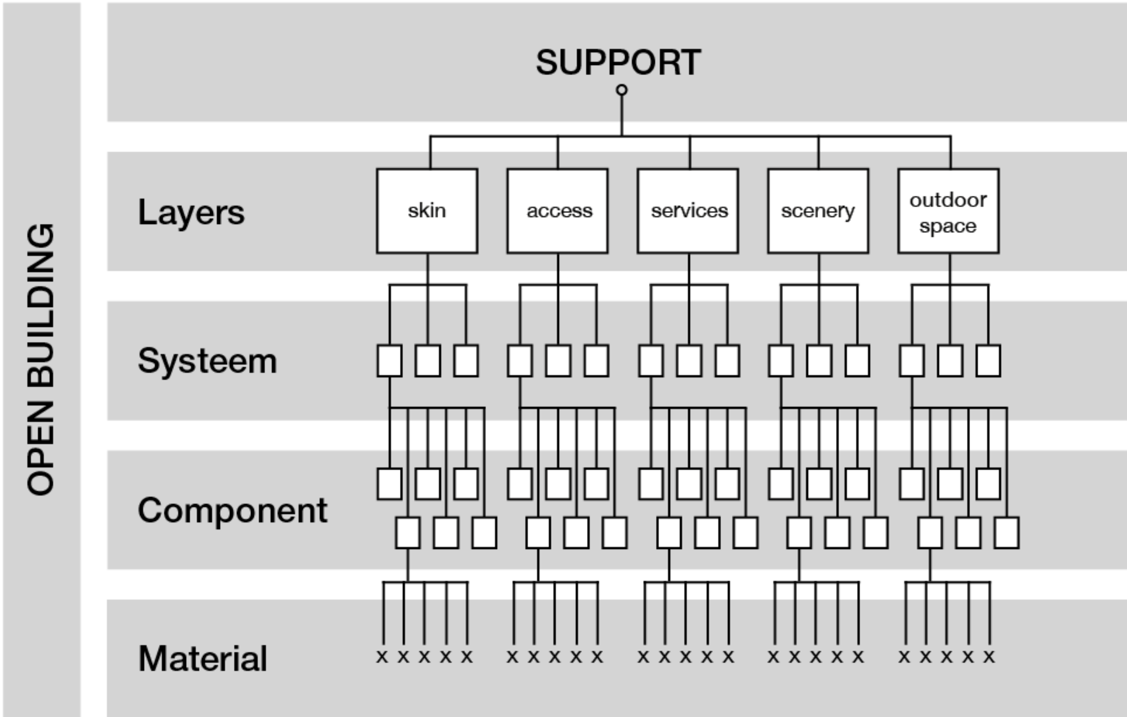

Figure 14 – Open building configuration; based on Durmisevic (2006)

Durmisevic (2006) describes six types of assemblies which show different relations between elements (fig. 15). The supports should act as a shared assembly. All building layers are only physical assembled to the support. The composition within each layer, systems and components should be either an open assembly or a shared assembly as much as possible. Building parts are independent from each other in these open hierarchies. Often a structure within a sub-layer of a building layer will be the base part for the total assembly which offers a lot of freedom.

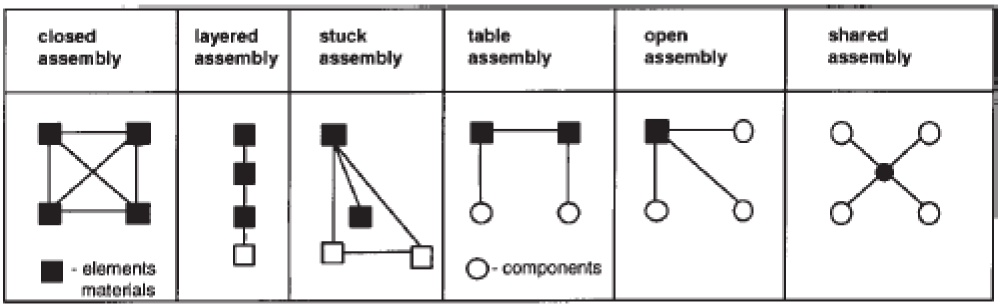

Figure 15 – Assemblies of different kind of relations between elements (Durmisevic, 2006, p. 172)

An example of an open assembly is shown in figure 16. The column (F1), which could be part of the support, forms an independent assembly with a structural function. The wooden frame (F2) can be disassembled easy from the column. At the same time it forms the base part for the façade components b1, b2 and b3. The components b, b1, b2 and b3 form together the façade system which is part of the skin layer.

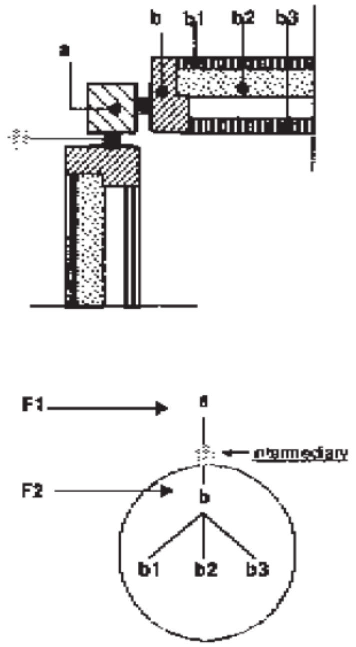

Figure 16 – independent assembly of two independent functions (Durmisevic, 2006, p. 176)

4.2. Disconnection

The physical connections of layers, systems, components and materials depends on the geometry of edges, the assembly sequence and the connection types. The geometry types can be divided in two kinds of physical containment. It can be an open geometry or an interpenetrating geometry (fig. 17). An open geometry is the most suitable for disassembly. An interpenetrating geometry is more dependent on the connected object. It can either be disconnected form just one side or it can't be disassembled without demolition of the connected object. (Durmisevic, 2006)

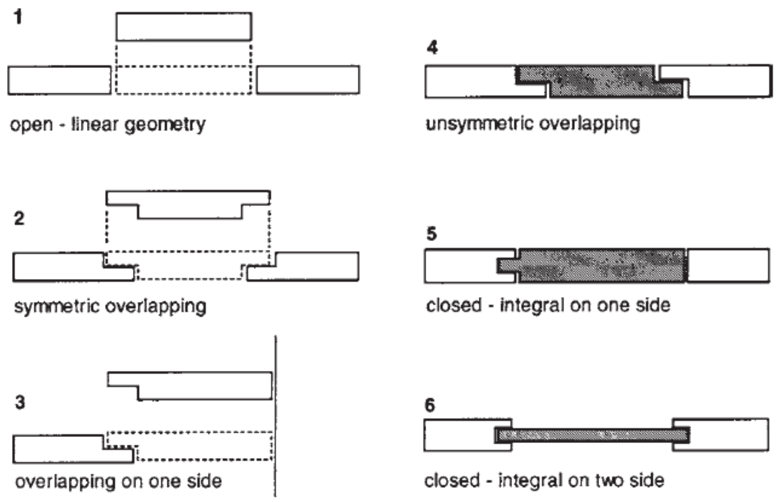

Figure 17 – Open geometry connection (1) and interpenetrating geometry (2-5) (Durmisevic, 2006, p. 178)

In figure 18 shows that disassembly can be done in two steps, because all elements are related to one component. This parallel assembly sequence can also speed up the process of disassembly. (Durmisevic, 2006) The connections should be free accessible. If this is not possible extra actions need to be taken, but they should not cause damage to other element. (Alba Concepts, 2019)

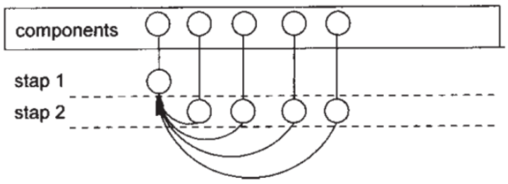

Figure 18 – Assembly sequence with base element (Durmisevic, 2006, p. 181)

There are three general connection types. Direct (integral) connections are part of the component edge which forms the entire connection. They can be overlapping and interlocking like the numbers 2-6 in figure 17. Disassembly is hard many times, because the components have shaped edges which only allow sequential disassembly. Indirect (accessory) connections are using additional components to create the connection. The additional component can be integrated in the component or can be external. External additional components are the most easy to disassembly, because internal connection components have a sequential (dis)assembly order. Filed connections can hardly provide an efficient circular flow, because these connections are filled on site. Examples are welded or glued connections, which are hard to disassemble.

Seven connection types are shown in figure 19. Most of them are hard to (dis)assemble. The most optimal connection is principle VII, which shows an indirect connection with an additional fixing component. When for instance object e3 is disassembled from C, the object e1 and e2 are still untouched. Elements and components are kept separately to avoid interference with other layers, systems or components. Besides, dry-jointing techniques are applied instead of chemical techniques.

Also principle IV, V and VI are assembled with dry connections, however these connections are more depending on other components. (Durmisevic, 2006) There are three kind of connection types in open buildings. Type 1 is between support and infill, type 2 is between two infill components within the same layer and the third type is between two infill components of different building layers. For type 1 and 2 the connection principles IV, V, VI and VII from figure 19 are suitable, because these connection don’t rely on other changeable building layers. Connection VII is the only suitable principle for type 3, because an indirect connection with an additional fixing device accommodates the independency of each infill building layer.

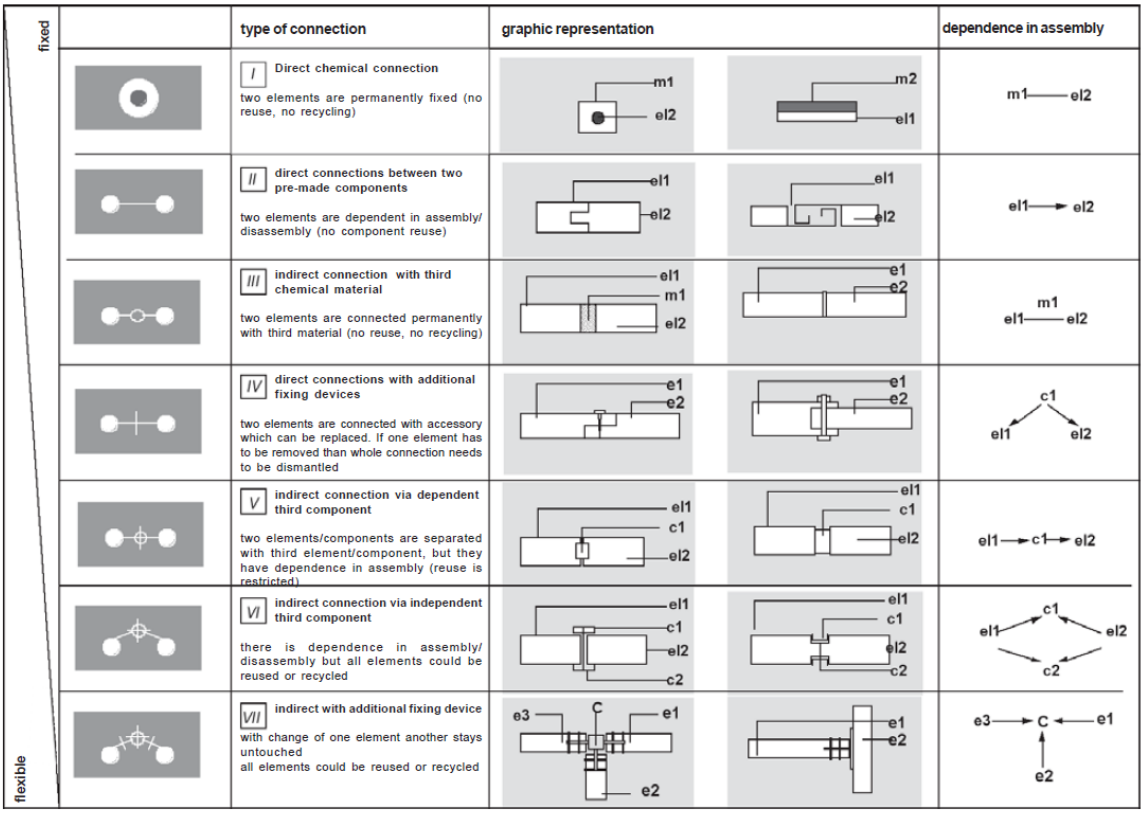

Figure 19 – Connection principles (Durmisevic, 2006, p. 183)

Dry connections can be realized with a free imposition, click connection, velcro connection or a magnetic connection. Connection with additional components are bolt-nut connections, spring connections, corner joints, screw connections, pins, dowels or other additional connecting components, but these connections are harder to disassemble compared to dry connections. (Alba Concepts, 2019) However, these connection have more physical potential. The connection type depends on the needed (physical) properties between elements. For instance, between the support and a façade system (skin-layer) a bolt-nut connection will function better than free imposition, a click-, velcro- or magnetic connection due to large vertical and horizontal loads that occur. The latter connections could be more common within the scenery or service layer. Scenery and service components are in general exposed to smaller loads and a shorter (functional) lifespan which means they have to be replaced more often.

CONCLUSION

The goal of this research paper was to offer a guiding structure and design principles for a support which provide maximum flexibility in function, size, program and appearance. A flexible support enables building layers to act independently so infill building layers, systems, components and materials can be adapted in a circular and sustainable way. The research has focused on a combination of theories (Habraken, Brand, Leupen) from a circular perspective and has given a definition of the relation between flexible supports and circular infill building layers. The design of an optimal support is based on these theories, an analysis of existing open buildings and mapping of layers and types. The independency of circular infill building layers is linked to design for disassembly principles between support and infill, within a single infill layer and between different infill layers.

The open building offers many possibilities for a circular and flexible building environment. The flexible support of the building can accommodate a circular flow of circular infill building layers. The support forms the frame which is the most permanent part of the building. The independent infill building layers can also be part of the permanent frame which forms a generic space in which change can occur. The circular infill layers have a different lifespan and can change independently from each other to accommodate an adaptable and circular flow. The building layers skin, access elements, service elements, scenery and outdoor space are all connected to the multifunctional support which forms a smart structure. The layer outdoor space has become more important in dense urban areas. Building volumes and outdoor space doesn’t have to be opponents. An extension of outdoor space on building can have many social, access and climatic functions and besides it can offer more greenery and biodiversity in the city. Support, infill and the independency of layers also offers opportunities for more user participation and mass customization. Too what extend user participation is integrated is the decision of the architect or contractor.

The most flexible structures found in the analysis are bay structures with stabilizing shearing walls. The design of the support depends on flexible and adaptable zoning of building layers and layer types. The zoning scheme of Habraken and the mapping of different layer types and zones shows the most optimal layout of the support (fig. 20). It has a uniform section and ideal proportions between façade length and created surface area. The zoning and dimensions which are based on a flexible infill, multifunctionality, climate performance, adaptability, daylight, façade length and materials offer a large variety of possibilities in terms of function, size and different user needs. The length and height of the total support configuration is variable and can be adjusted to the local situation.

Design for disassembly is essential to provide a circular building infill. A systematization of the composition of building layers in relation to the support is shown in figure 21. Layers, systems, components and materials are clustered by function which minimalizes the interference between them. Open or shared assemblies are created by configuration of elements which have only one relation with a parent element. The edges of the connecting elements should be open which makes it more independent from the connected object. Connections with additional fixing devices or third components can be applied between support and infill or between systems/components within one infill layer. Between two different infill layers only an indirect connection with an additional fixing device should be used. When disassembly layer X from an indirect additional fixing device, layer Y will be stay untouched. Dry connections are the most easy to disassembly. However, the specific connection depends on the function and the needed (physical) properties of the connection.

The research question is ‘’How can a flexible support be designed for a circular and multifunctional open building?’’ A answer is summarized in figure 20 and 21. The support is a smart structure with specific zoning and dimensions. It can change easily by replacing the circular building layers which are made for disassembly in a hierarchic configuration of layers and systems in which each elements is connected to a parent element. The support offers the key to a circular future and providing flexibility and optimal use of materials while offering a frame for all kinds of functions and people.

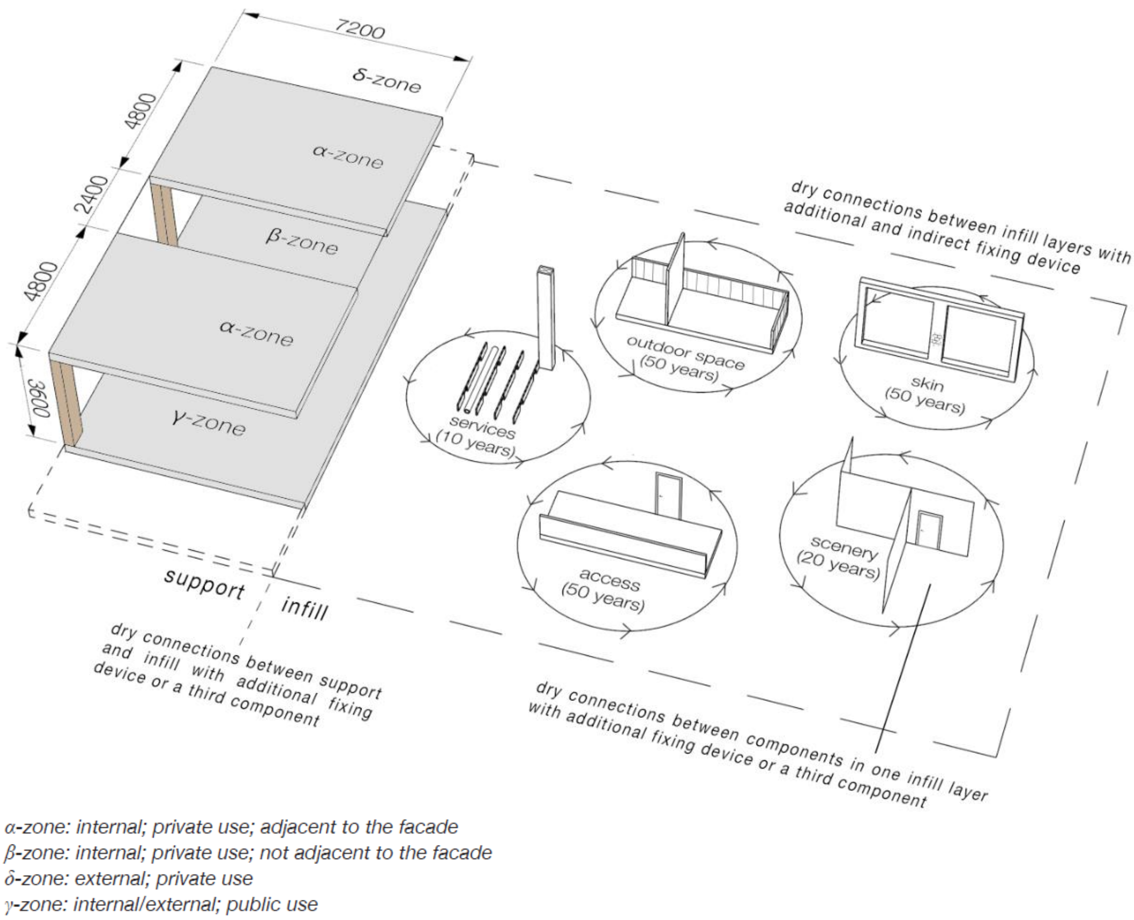

Figure 20 – Conclusion drawing of the flexible support which accommodates circular building layers

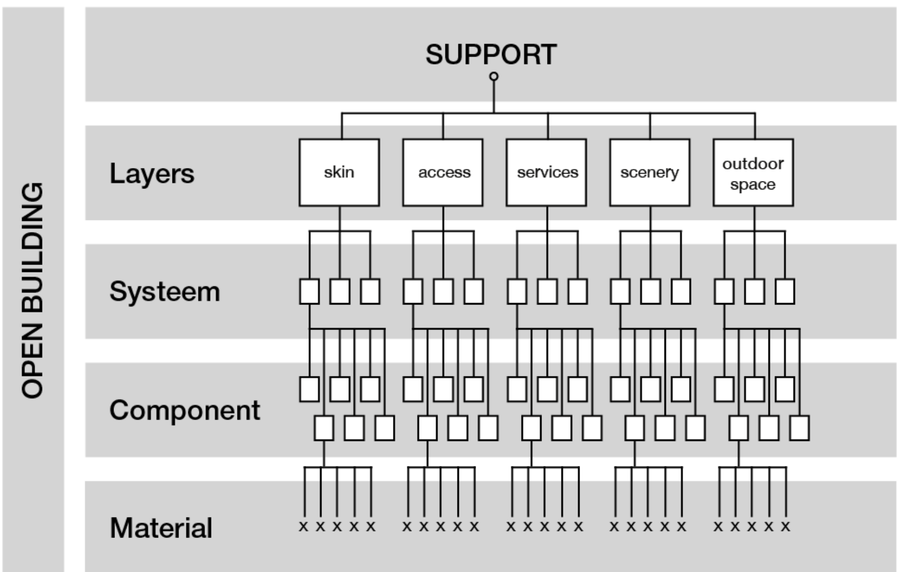

Figure 21 – Open building configuration

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APPENDIX 1 – CATALOG ANALYSIS OPEN BUILDING

APPENDIX 2 – ANALYSIS STRUCTURES WITH OUTDOOR SPACE

APPENDIX 3 – ZONING OPEN BUILDING CASE STUDIES

APPENDIX 4 – LAYER TYPES AND ZONING SUPPORTS









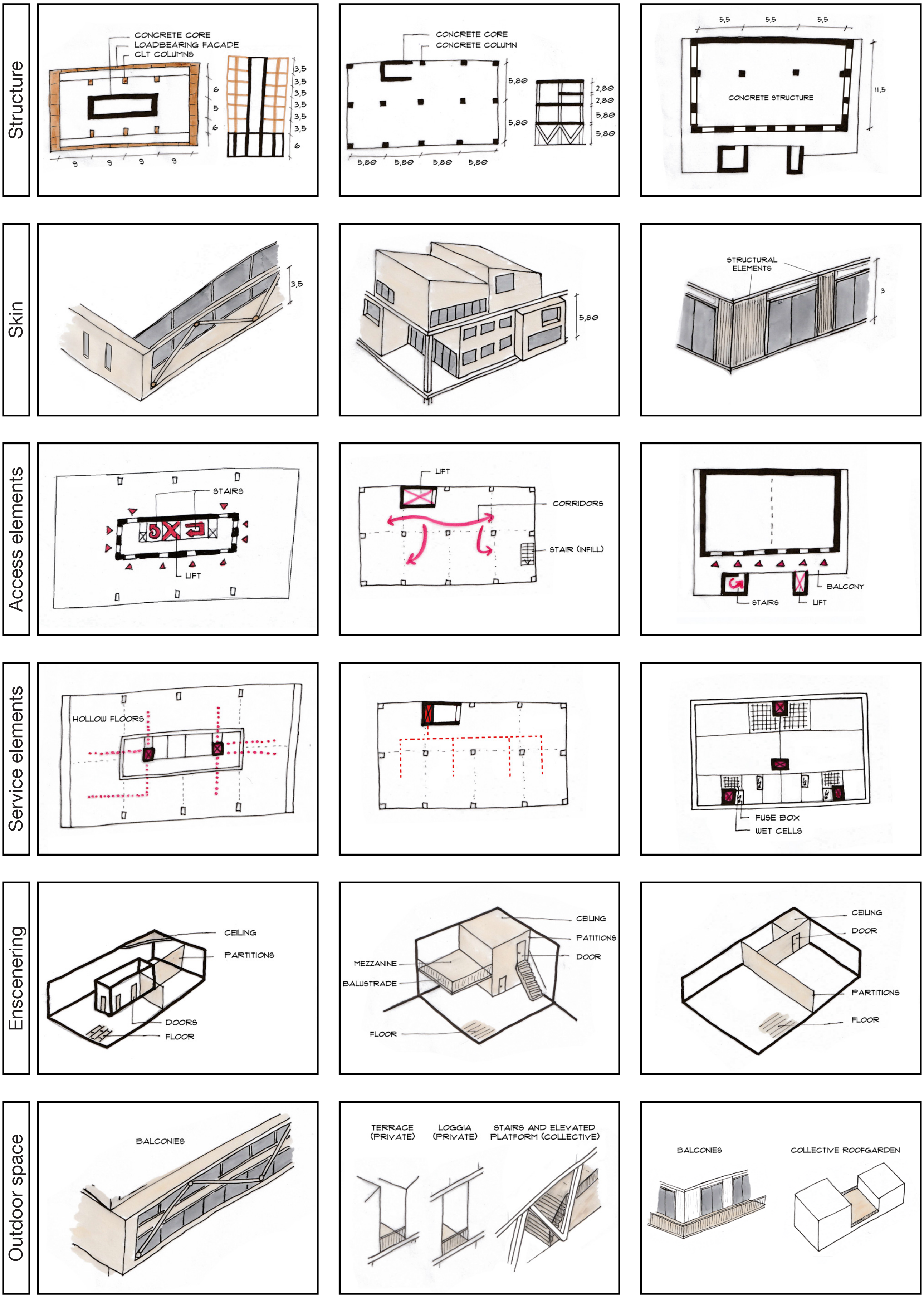
appendix 1

catalog analysis open building

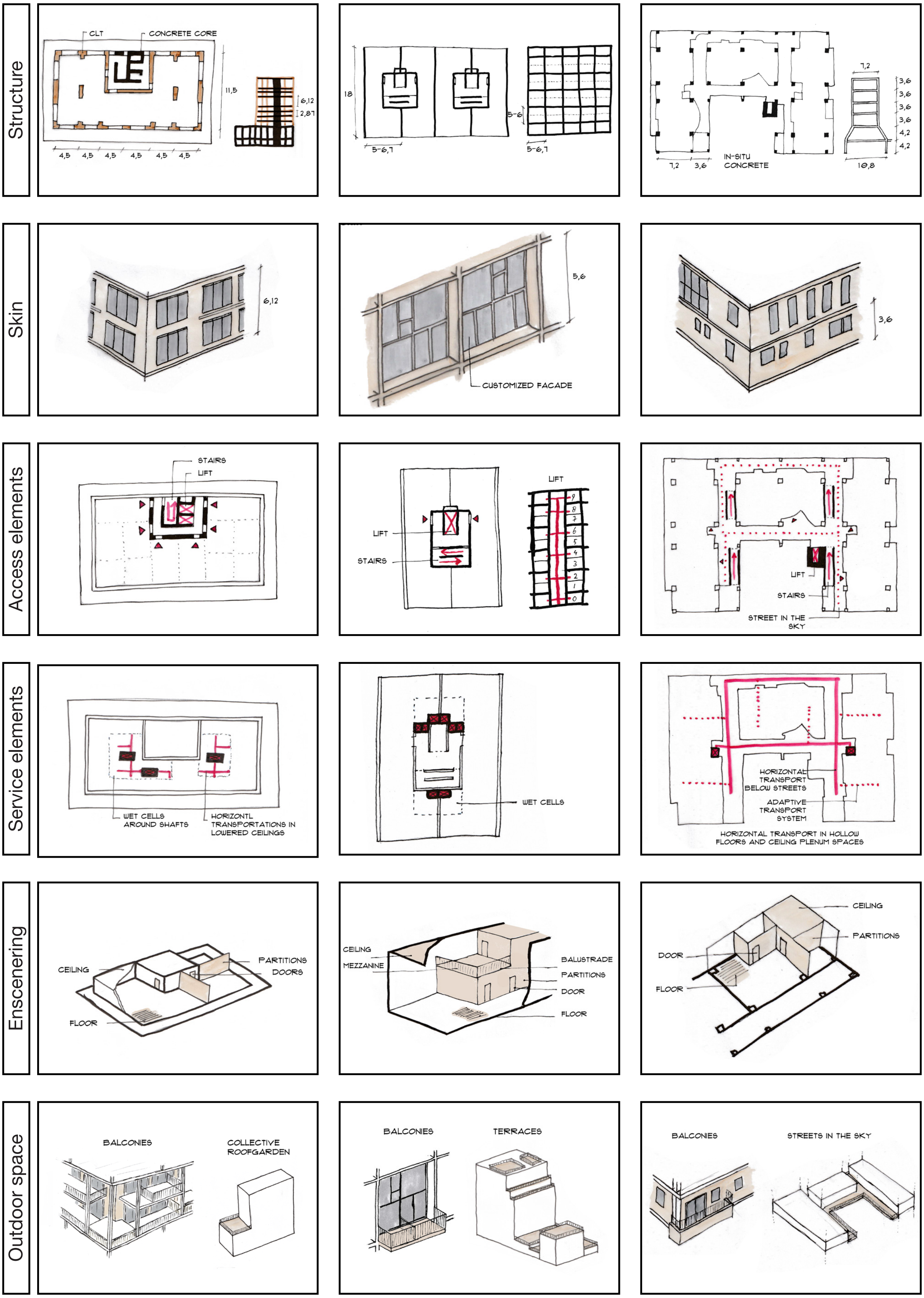
Patch 22 (2016)
Frantzen et. al - Amsterdam

Object One (concept)
Space & Matter - Deventer

CiWoCo (2019)
GAAGA - Amsterdam



Stories (2020) Olaf Gipser - Amsterdam	**Superlofts Houthavens (2016)** Marc Koehler - Amsterdam	**Next 21 (1994)** Yositika Utida - Osaka

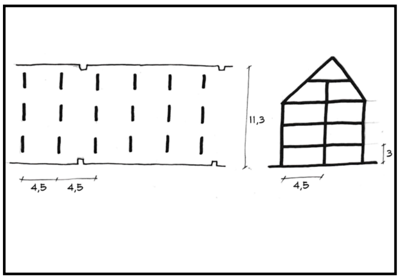


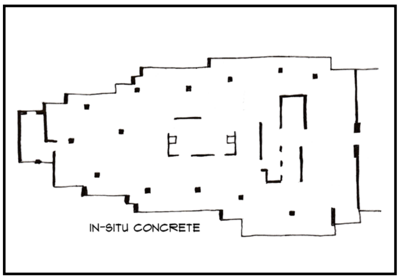
Molenvliet (1978)
Frans van der Werf - Papendrecht

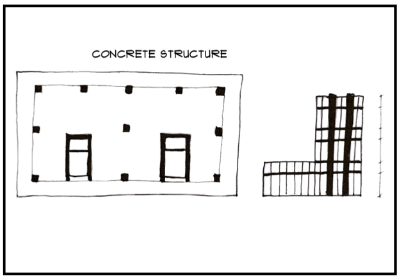
Maison Medicale (1974)
Lucien Kroll - Brussel

Hoge Vrijheid (2020)
Martijn van der Hijden - Den Haag

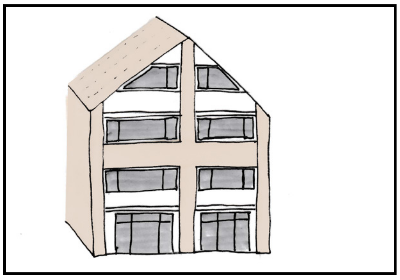
Structure

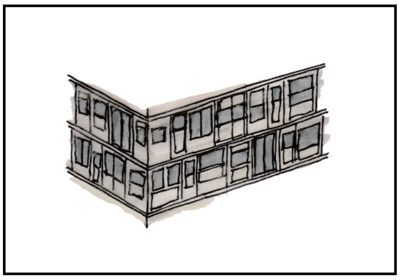


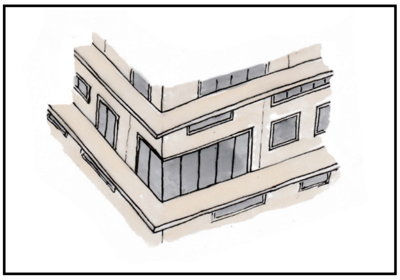




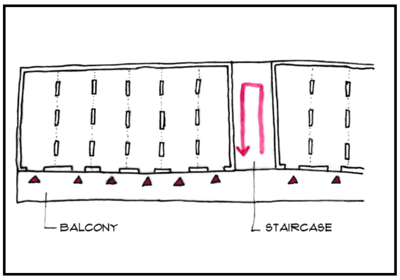
Skin

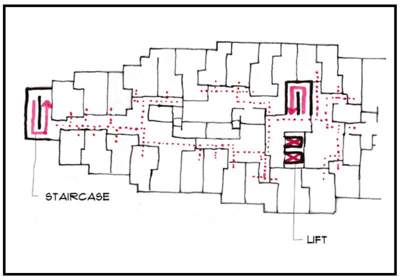


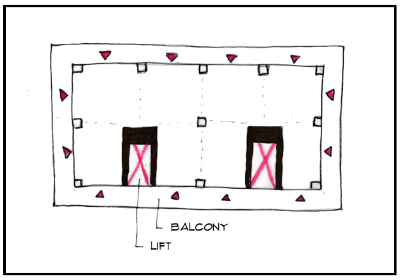




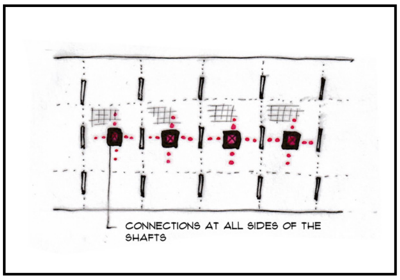
Access elements

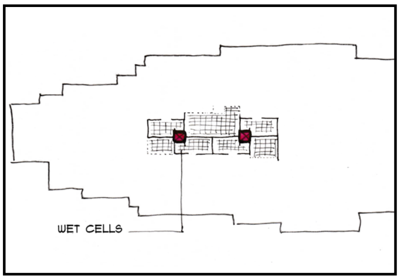


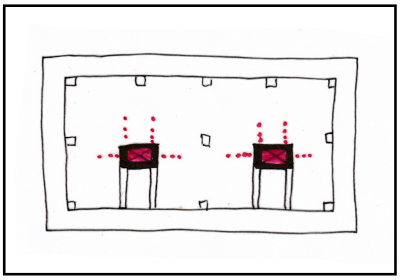




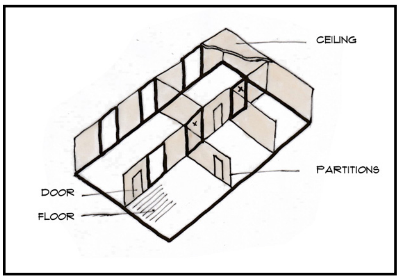
Service elements

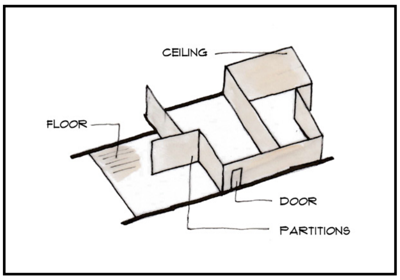


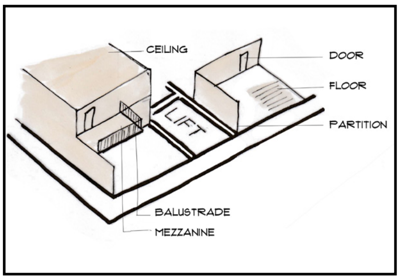




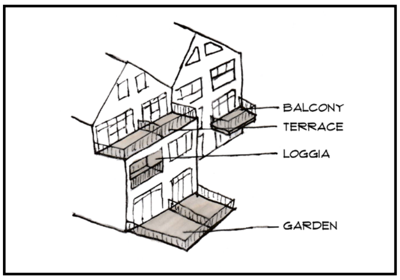
Enscenering

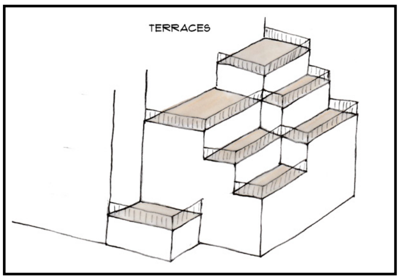


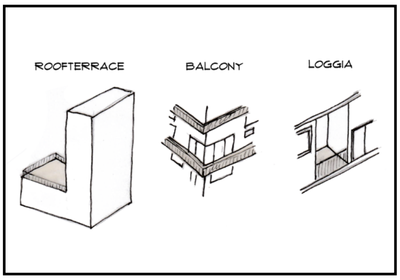




Outdoor space

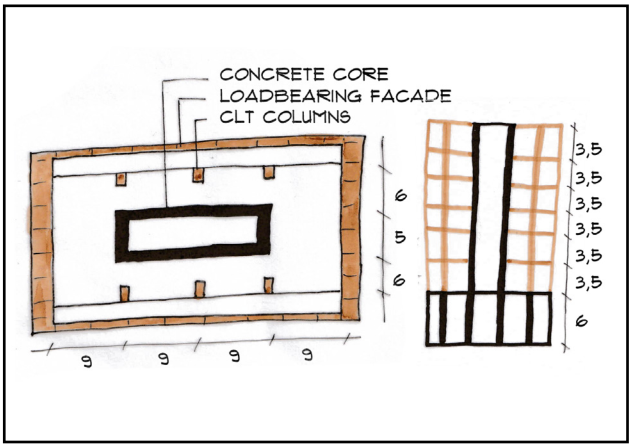




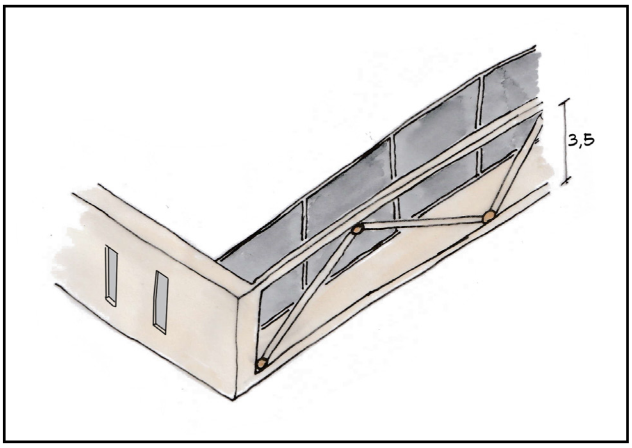


Patch 22

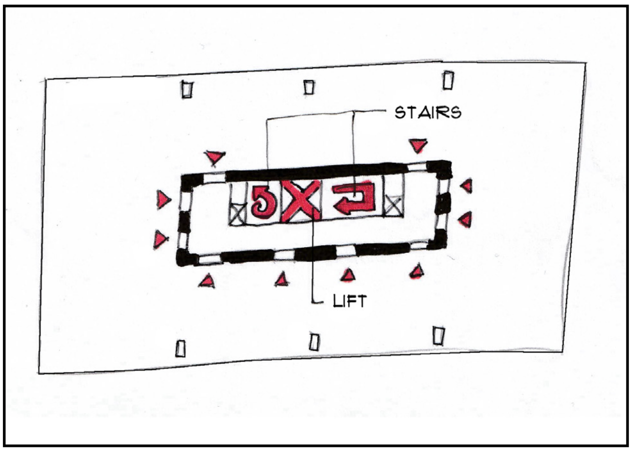
Frantzen et. al
Amsterdam - 2016



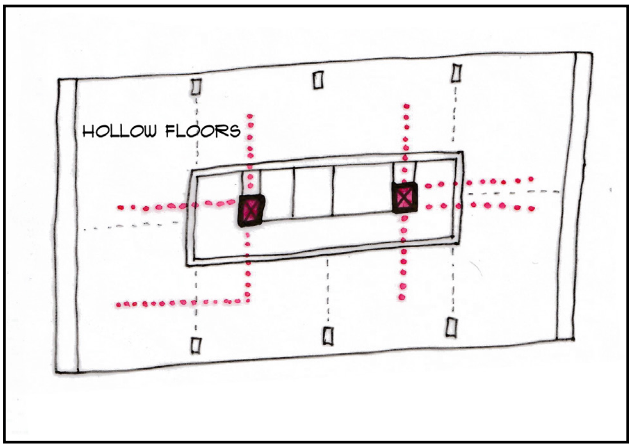
Structure
The structure consist of a grid system and is stabilized by a concrete core. Columns are made of crossed laminated timber and floors are also made of concrete. The core is situated in the middle of the buildingblock. The combination of the bearing facade, slab-columns, concrete floors and central core makes the 9 meter span possible which results in very flexible indoor space. The floorheight is 3,5 meter which makes the building suitable for work spaces and appartments. The structure is orientated to the front of the building which is perpendicular on the glass front facade.



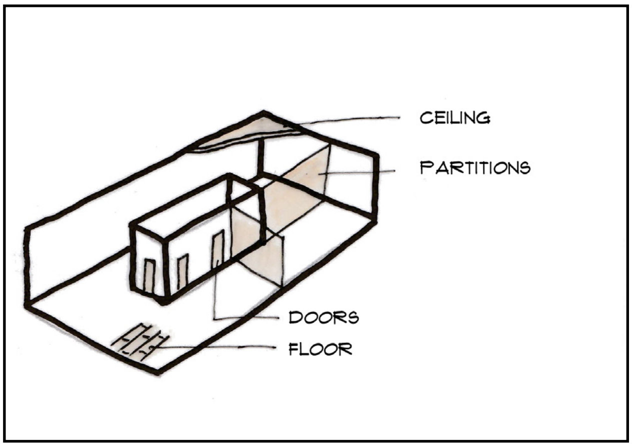
Skin
The horizontal orientated facade consist of a glass front at the north and south side. The glass front has been set back because of the present balcony. At the east and west side, small vertical windows are placed within the bearing facade which results in a less flexible facade, but a more flexible indoorspace. The functions of the building are not visible through the facade. The facade as a whole is part of the permanent structure, however some elements like the windows are easy replaceable.



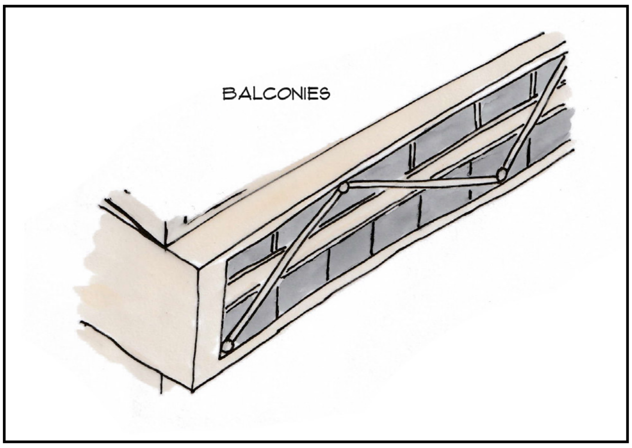
Access
The six levels of the building are accessable by two staircases and a lift which are situated in the building-core. The two stairs can both function as an escape route. In the core of each floor is a corridor. There are ten openings which can be used as an entrance. This means that on each floor ten different units are possible with their own front door. This makes the whole floorplan even more flexible.



Servant elements
The shafts which accomodate the vertical transport are located in the core. The horizontal transport is adaptable because of the hollow floors and the removable top layer. This means the location of wet cells like kitchens and toilets are not depending on a near by vertical shaft which makes the interior compartmentalization very adaptable. The connection points for pipes are located at the core.



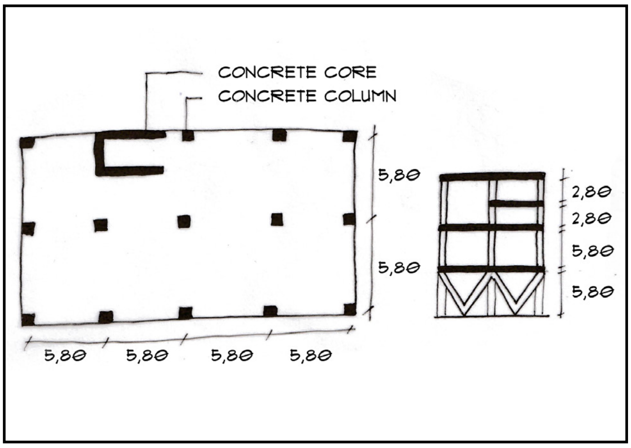
Scenery
Partitionwalls can easy be installed to compartimentize the interior space. Doors can be added in the core openings (see access) so each unit is accessable. The owner can add and adapt floor and ceilings to make the space conform his own requirements for a commercial or residential space. Occupants can completely arrange their floorplans which makes each floor very flexible.



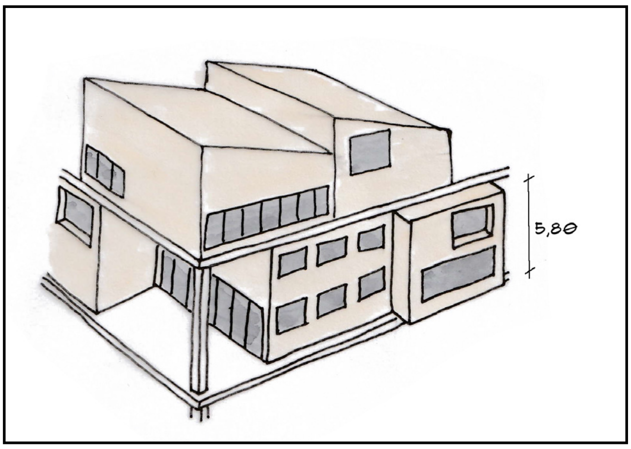
Outdoor space
At the front and the back balconies are installed. It is the only outdoor space of the building. The balconies are set back from the front facade which makes it a pleasant space on a windy day. It is easy to combine several balconies, because it has a continious floor.

Object One

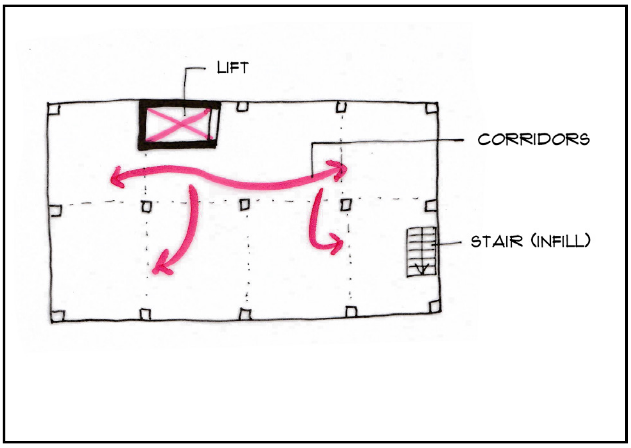
Space & Matter
Deventer - concept



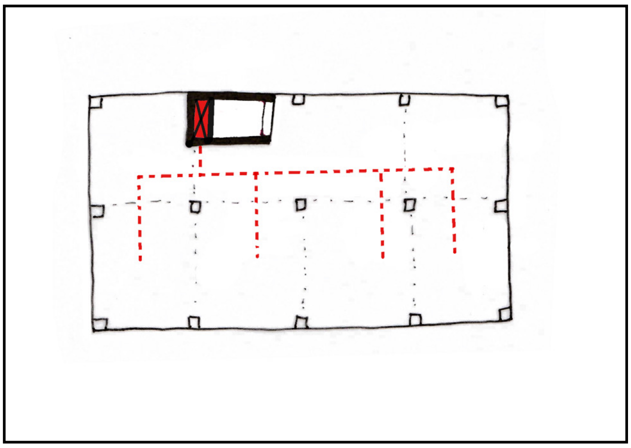
Structure
A grid system with single bay bracing and shear wall stabilization forms the structure of Object One. The robust concrete structure has a strong appearance in the building. The concrete floors are connected by concrete columns which makes the structure very flexible. The columns are placed in a grid of 5,80m. The floorheight is 5,80m which makes it possible to make double layered units. Withhout the infill the structure looks like the Dom-Ino House of Le Corbusier. No structure has no specific direction in the floorplans, however the concrete floors have a very present horizontal direction in the appearance of the building.



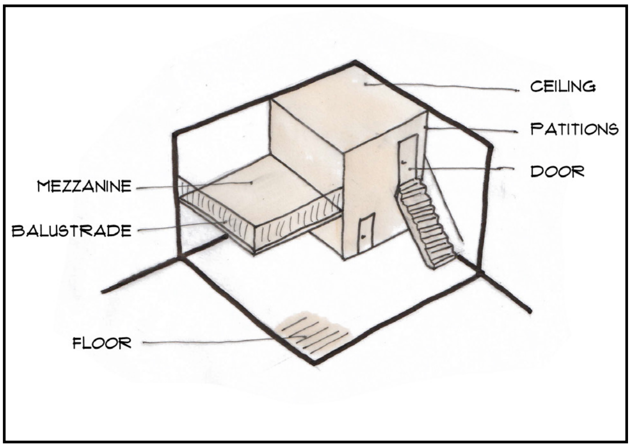
Skin
The skin of the building is completely flexible. All units have different windowopenings of different sizes and heights. The units are not always placed against each other, which leaves inbetween space between the units. This results in longer facade length relative to the surface area. The skin is very adaptable, however the interventions of the skin will be quite radical since there is no facade framework and the facade does not belong to the permanent support.



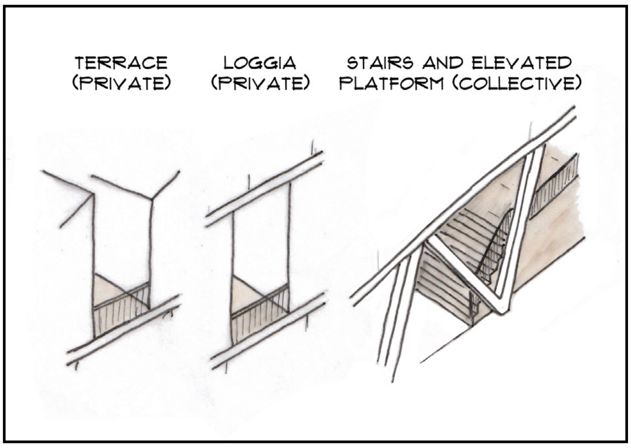
Access
The lifted floorlevels can be reached by the elevator which is located at the side of the structure. The free layout of each floor makes the horizontal access elements completely flexible. Corridors and galleries can be placed in dialogue with the occupants.



Servant elements
The shafts are placed in the core. From here the horizontal transport is completely adaptable. The positions of wet cells is completely free.



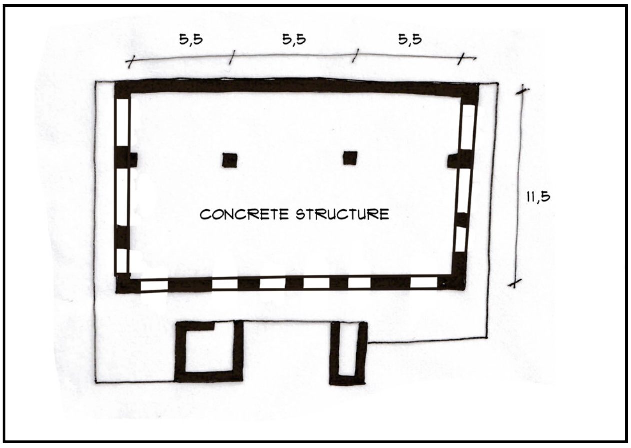
Scenery
In each unit partition walls can be placed anywhere. Doors, floors, ceiling, mezzanines and balustrades can be placed in such a way which fulfill the needs of the occupant. The only boundaries within the adaptability are formed by the structural- and access elements.



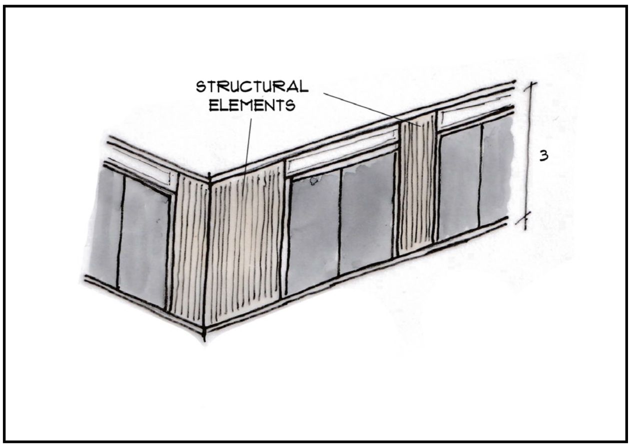
Outdoor space
Terraces, loggia's and outdoorcorridors are in the inbetween spaces on the different levels of the building. These outdoor spaces create openness and light in the building. The lifted outdoor space are used as lifted streets. At the ground level a wide staircase leads to an public elevated platform.

CiWiCo

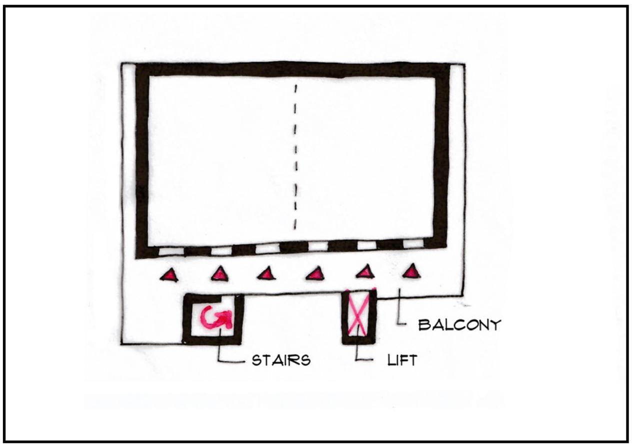
GAAGA
Amsterdam - 2019



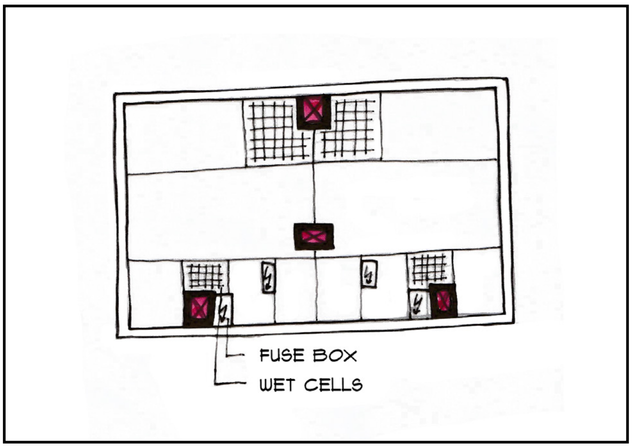
Structure
The building consist of two building blocks which are connected by a parking garage. One of the blocks (with eight appartments) is present here. The floors are about 11,5 meter by 16,5 meter. The structure is made of prefabricated concrete casco's. The two-way wall system in the facades consist of vertical slabs which makes the interior very flexible. Approximately in the middle of each floor two columns are placed with a distance of 5,5 meter of each other. The generous floorheight makes the structure suitable for housing and office spaces.



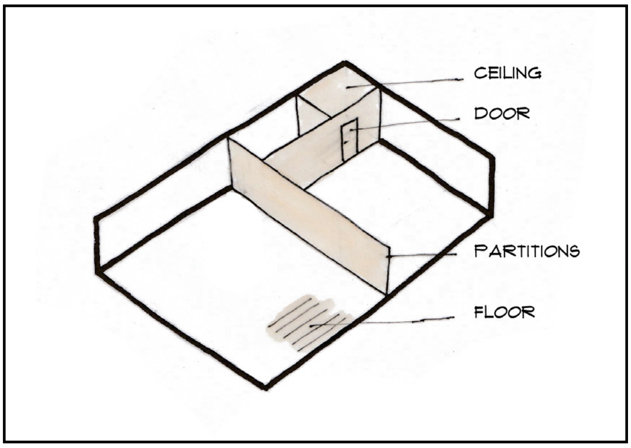
Skin
The facade consist of a variation between glass fronts and a closed finishing of sheet pil profiles of Azobé. The glass fronts allow a lot of daylight in the building. The facade is completely made of flexible components which makes it easy adaptable for future use.



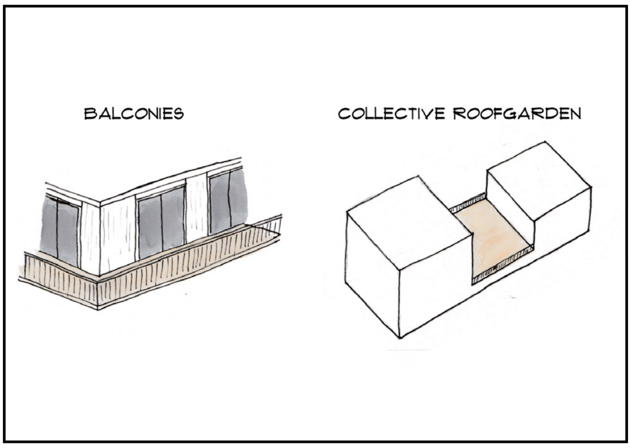
Access
The access to the appartment is quite special. A semi freestanding elevator and staircase leads to the balconies which are functioning as lifted streets around the building block. From the balcony six entrances at each level are possible to access the units. The multiple entrances makes the building usefull for living and working next to each other with a separated entrance.



Servant elements
Shafts are placed next to the wet cells in the building. The horizontal transport is through a lowered ceiling. Retention walls are placed around the shafts so services can be easily adapted. The floor layout is less flexible because of the fixed location of wet cells.



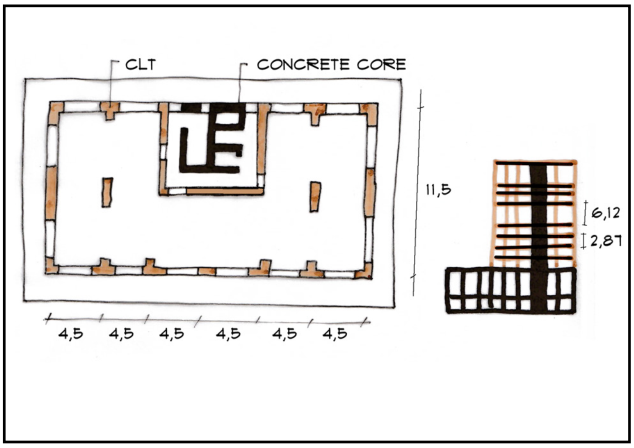
Scenery
Partitionwalls can be placed to compartimentize the indoor space. Also doors, floors and ceilings are adaptable to make the space conform his own requirements. Occupants have the possibilty to make a seperate workspace or guestroom with a seperate entrance.



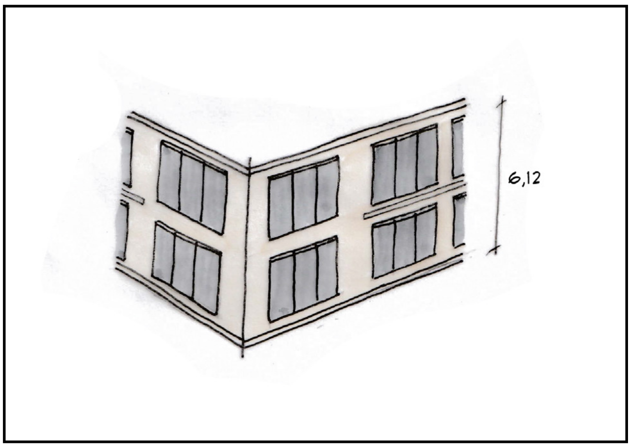
Outdoor space
The balconies function as lifted streets. Besides their function of accessability they can be used to sit outside. For all residents is a collective roofgarden on the parkinggarage. The green roofgarden functions also as a waterbuffer.

Stories

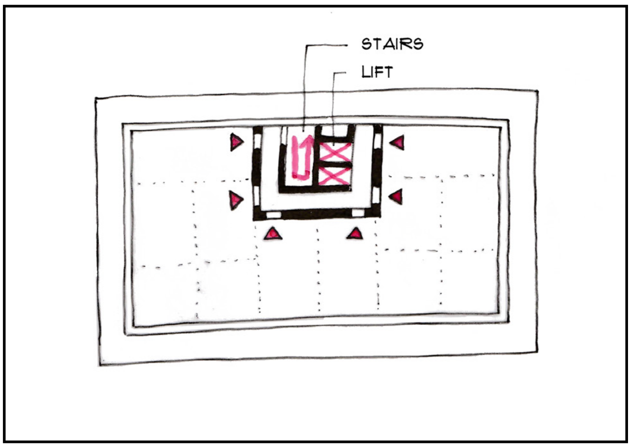
Olaf Gipser
Amsterdam - 2020



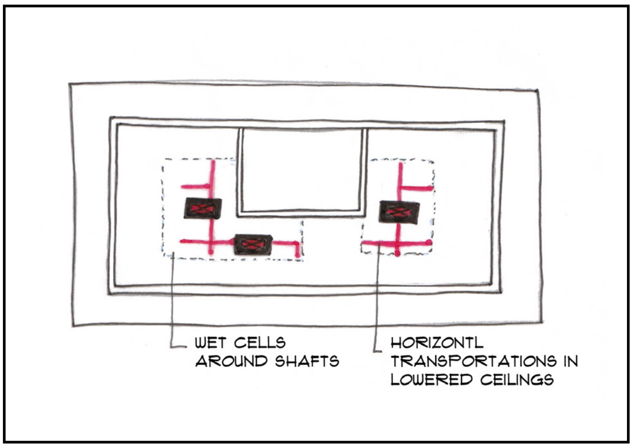
Structure
The structure is a grid system with core stabilization and two-way wall system with large cut-outs. The first two floors and the core of the building are made of concrete. The rest of the structure is made of crossed laminated timber. The floors are about 11,5 meter by 27 meter. The core is situated in the middle against the facade. The vertical bearing elements are the core and CLT portals. The distance between the facade and the slab-columns is 4,5 meter. The floorheight is 2,87meter or 6,12 meter The double floorheights makes it possible to build a additional floor. The dimensions of the upper floors are designed specifically for housing units.



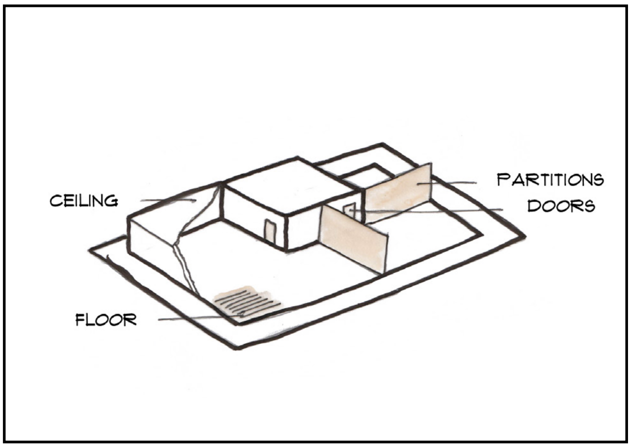
Skin
In the facade consist of large windows on all sides. These large windows are needed, since daylight is partly blocked by the overhanging balconies. Doors to the balconies are installed. The facade and the roof are part of the more permanent structure. The skin has a normal lifespan which means facade components can not be replaced by the residents.



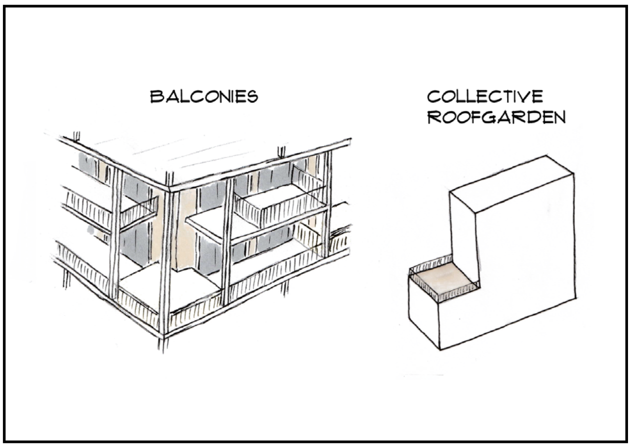
Access
The building levels are accessable by a staircase and two lifts which are situated in the concrete building core. A corridor around the lifts and staircase provide acces to the units. Six openings can be used as an entrance, which results in a maximum of six units per floor.



Servant elements
Three shaft are situated seperately at a strategic place between two possible units on each floor. The wet cells like kitchens and bathrooms are situated around the shafts, because the connection point are also there. Lowered ceiling provide the horizontal service transportation. Sewerage installation and mechanical heat recovery ventilation are placed in direct connection to the shafts. Only water and electricity are placed in the core of the building. The location of the shafts limit the possibilities of the interior compartmentalization.



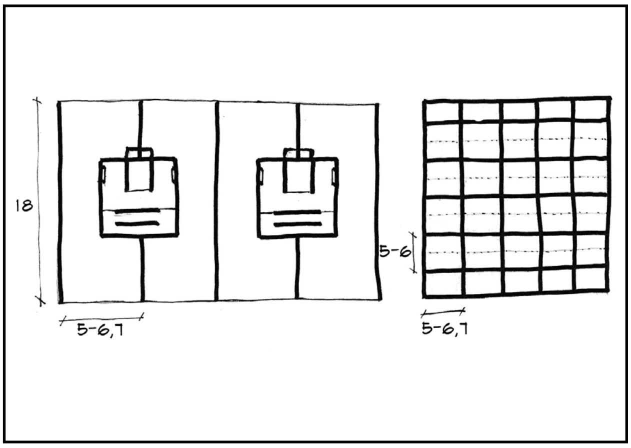
Scenery
Partitionwalls can be installed to create the floorplan conform the requirements of the tennants. Appartments can be made bigger and smaller which is provided by the flexible structural layout. Also interior doors, floors and ceiling can be adjusted. However, the flexibility of the interior space is limited by location of the wett cells and the relatively small single floorheights.



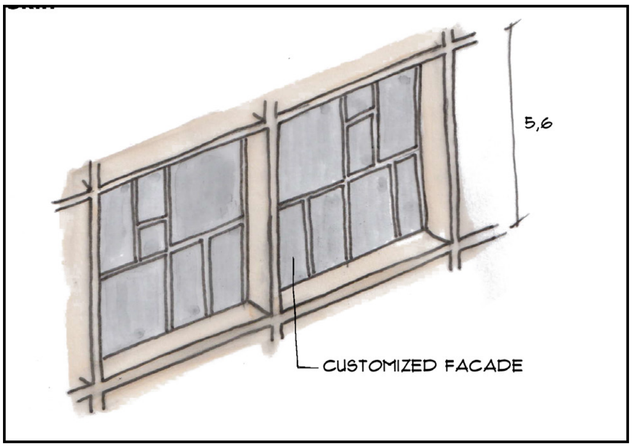
Outdoor space
All around the building balconies characterize the appearance of the building. Continious balconies have double-heights and inbetween these seperated balconies are installed. The whole balcony structure is made out of steel and is seperated from the concrete/clt structure. Inbetween these steel structures are niches for the trees which function as natural privacy screens. A collective roof garden is situated on the lower rooftop. Tennants can use the rooftop for meeting each other and use the garden for urban farming. The outdoor space is part of the permanent structure, however the seperated balcony structure could be removed.

Superlofts Houthavens

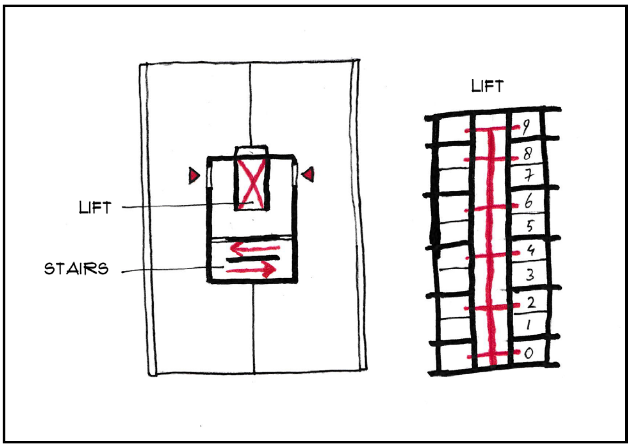
Marc Koehler
Amsterdam - 2016



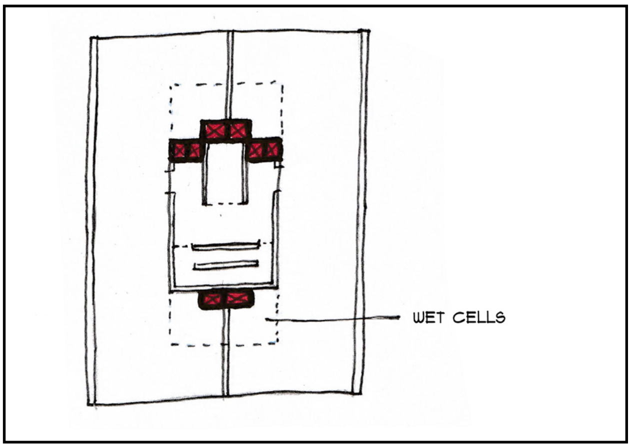
Structure
The structure consist of a casco concrete longitudinal wall system. The structure has a clear orientation created by the longitudinal walls. Two lofts are placed back to back to each other with in the middle a core. Bays have a width between 5 and 6,7 meter and a depth of 18 meter. The floorheight of 5 meters gives the tennants maximal flexibility and the opportunity to expand the floor with 70%. The flexibility in the width is very limited, because there are no cut-outs in the walls. It is not possible to combine multiple lofts.



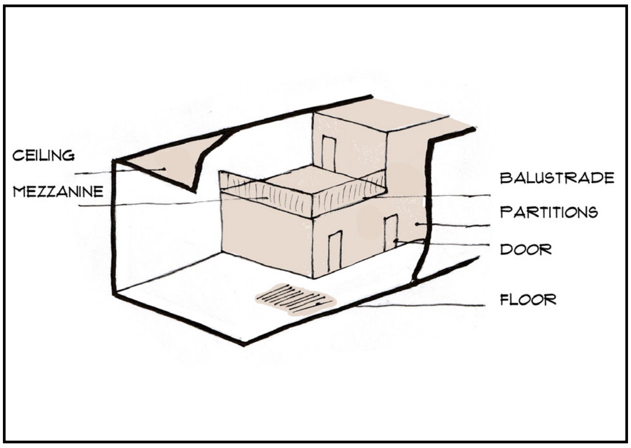
Skin
The facade consist of different elements which gives the stacked lofts a diverse appearance. Occupants could choose the between different configuration of window openings, which makes each loft unique. The facade is easy replaceable after its lifespan. It is placed in a frame which seperated form the structure. Doors in the facade offer access to the balconies which are situated on both side of the building.



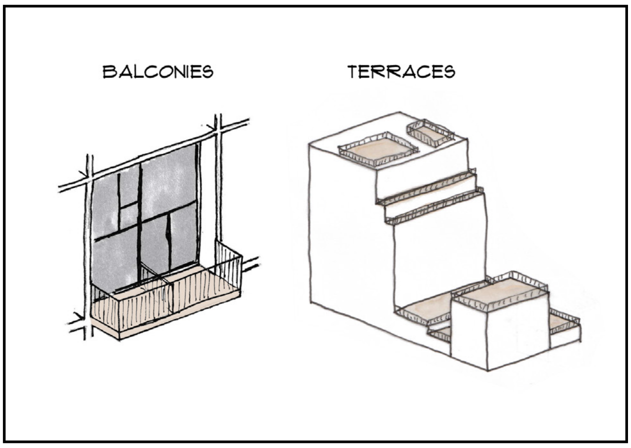
Access
The lofts are placed back to back with in the middle a core. The lift and the staircase are situated in the core. Tennants only have acces to the upper floor of their lofts. The lift only stops at level 0, 2, 4, 6, 8 and 9. From the core only one entrance leads to the lofts. Collective access elements are not adaptable. Only within the lofts tennants have a lot of personal freedom in their layout.



Servant elements
Shafts are situated which accomodate the vertical transport are located in and adjacant to the core. All access points are at the shafts, which means all wett cells should be adjacent to the shafts. Because of this the interior compartmentalization is limited. The location of kitchens, bathrooms and toilets will be around the shaft.



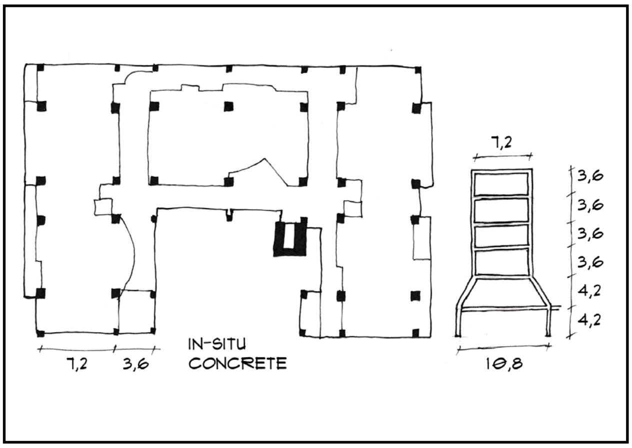
Scenery
Within the concrete casco's many configuration are possible to personalize the complete interior space to the needs of the occupants. Partitions walls, doors, floors, ceilings, mezzanines, balustrades can all be added or removed. The generous height between 5 and 6 meters makes it possible to make an extra floor.



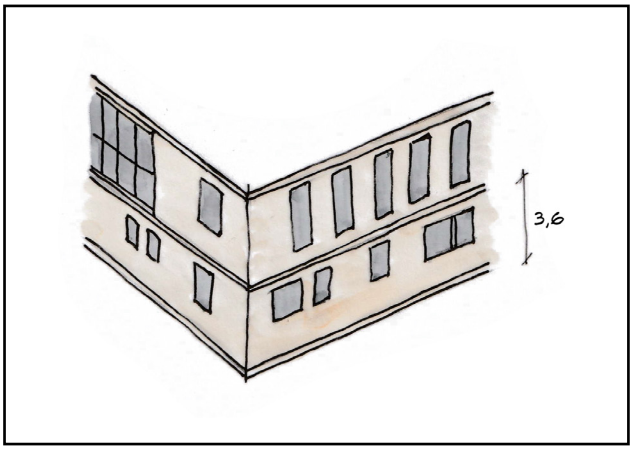
Outdoor space
All lofts have an own private balcony. The structure of the balcony is seperated from the bearing structure. which makes it possible to disconnect them. The balconies are partly set back from the front facade to create more private space.
Besides the balconiese terracces are placed at the roof top and on the parking garage.

Next 21

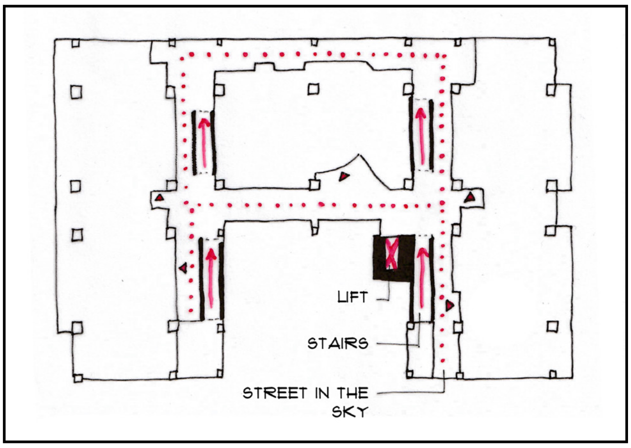
Yositika Utida
Osaka - 1994



Structure
The structure consist of framed bays of concrete which offer a lot of flexibility. At the grond floor the structure has a grid of 10,8 meter, but from the first floor this changes to a grid of 7,2 meter and the adjacent lifted street has even a smaller grid of 3,6 meter. Rigid connections result in a robust structure which result in the strong appearance of the building. The level difference is at the first two levels 4,2 meter and in the rest of the building 3,6 meters.

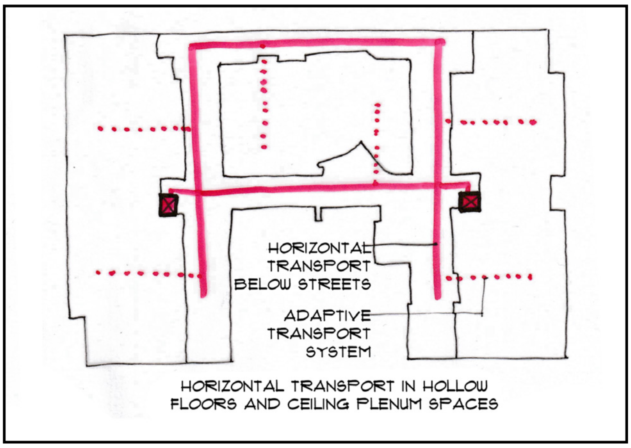


Skin
The facade of the building is very flexible. All units have different windowopenings of different sizes and heights. There are no bearing elements in the facade which means it could be replaced easily. The geomatrical variations in the facade are coordinated using design rules.



Access

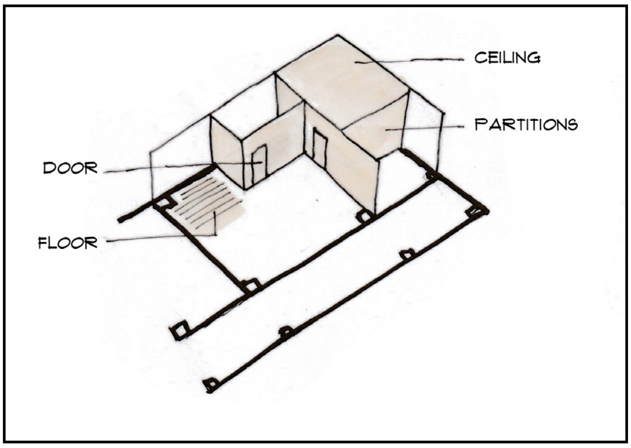
The levels of the building are accessable by two staircases and a lift which are connected to the lifted streets. The lifted provide horizontal accessability and brings the occupants to the entrance of their house. The two stairs can function as an escape route. The lifted streets provide a lot of flexibility because everywhere along the lifted street an entrance can be located.



Servant elements

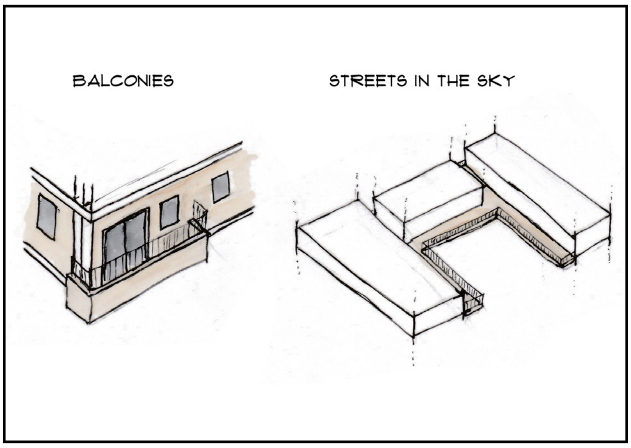
Shafts are place on both sides of the building. Hollow floors and suspended ceiling provide space for horizontal transportation of services. In the structure of the lifted streets (or exterior corridor) utility zones are located for pipes and electricity.

The location of wet cells is completely free to the inhabitans.



Scenery

The structure, access elements and service elements offer a lof of freedom in the interior compartimentaziation of the building. Partitionwalls and doors can be installed and adapt to change the layout to the needs of the owner.



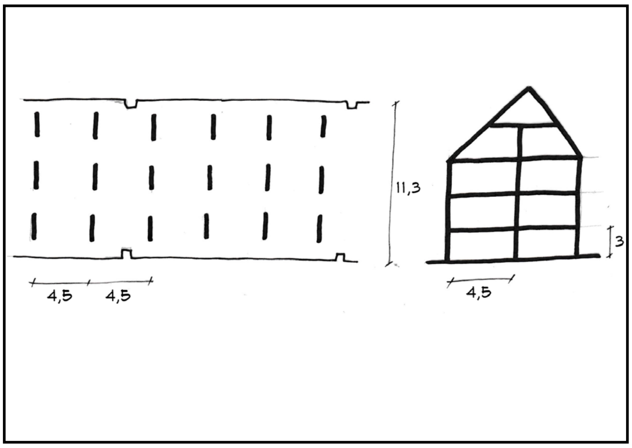
Outdoor space

On the outside of the building some balconies are installed. These provides the owner private outdoor space.

The lifted streets is besides his access function used as collective outdoor space. The lifted street is integrated in the building, because it is situated on the inside of the structure. This makes the street also less adaptable, because it is harder to disconnect this layer.

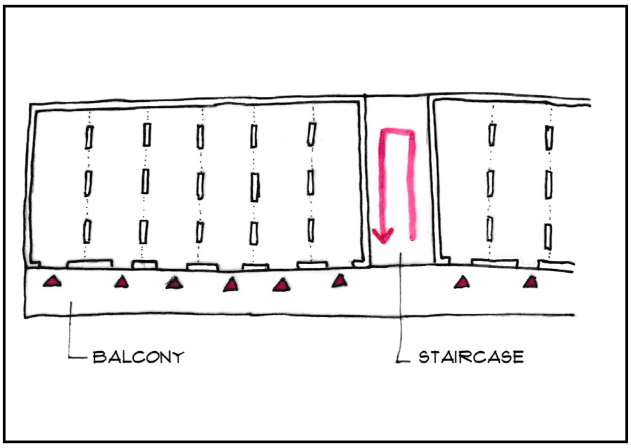
Molenvliet

Frans van der Werf
Papendrecht - 1978

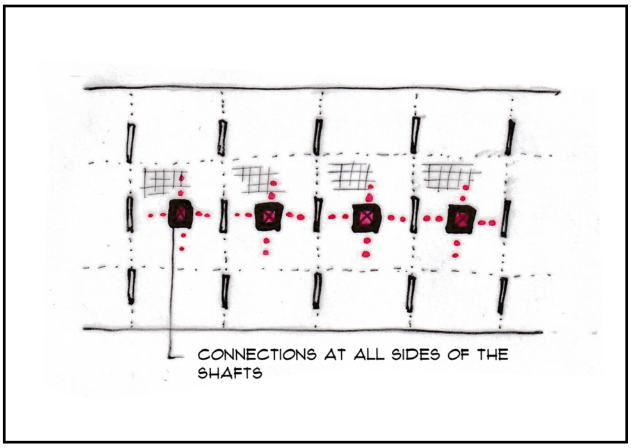


Structure
The structure is a grid system of longitudinal walls of concrete. The vertical structure elements are walls or slab-columns which are placed perpendicular on the facade. Between each wall is an open space which makes it possible to combine different units with each other. The walls or slab columns give the structure already an orientation and spatial quality.

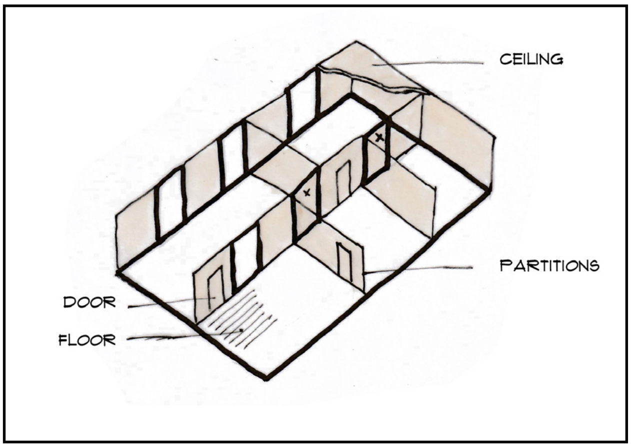
Skin
The skin consist of different kind of openings. Occupants could choose a window frame type to make the house more individual. Some windows are set back, because of a loggia. The parapet height and the total window height is the same everywhere. The dwelling function is clearly visisble in the facade. Windows can be replaced in the style of the building when the needs of occupants change.



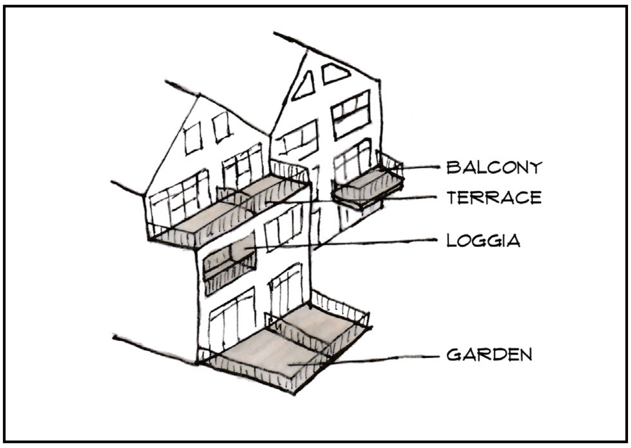
Access
A lift and staircase are placed between about five or six units. These vertical access element leads to an outdoor gallery. Te gallery leads to the entrances of the units, which is very flexible since they can be placed everywhere along the facade.



Servant elements
Shafts are placed in the middle of the units between the two outer walls. This location gives a lot of freedom to the location of the wet-cells. In the future is should be easy to replace and relocated the bathroom. Connection points are placed on all sides of the shafts. fuseboxes are integrated in the sleeve of the shafts.



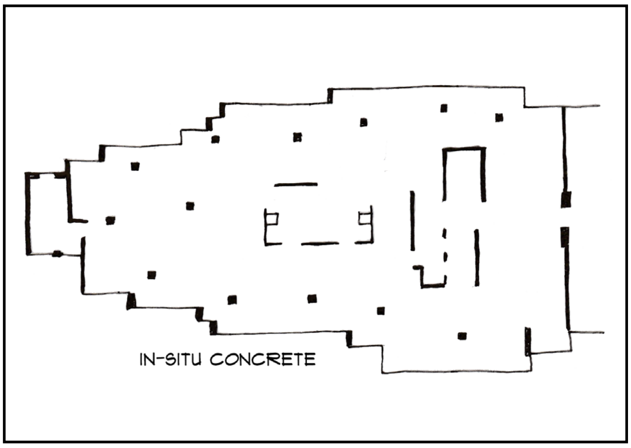
Scenery
Partitionswalls can be installed to compartimentize the interior space. The owner can add finishings of the floor and the ceiling. Rooms can be added by splitting up larger rooms so the interior is conform the needs of the inhabitants.



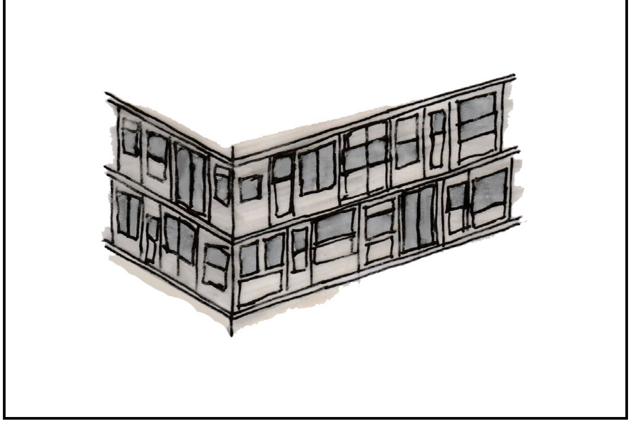
Outdoor space
The project is charachterized by the different kind of outdoor spaces. The buildings are built around collective courtyards. The units have private gardens, loggia's, terraces or balconies. The project is aimed to a divers group of people with their own needs. Most private outdoor spaces are not adaptable. Only the gardens could be reorganized quite easy.

Maison Medicale

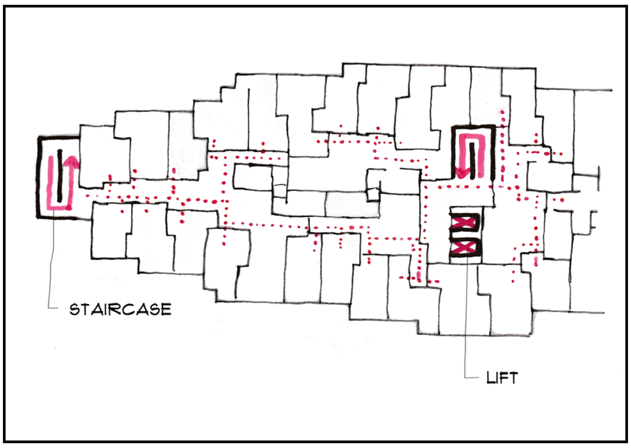
Lucien Kroll
Brussel - 1974



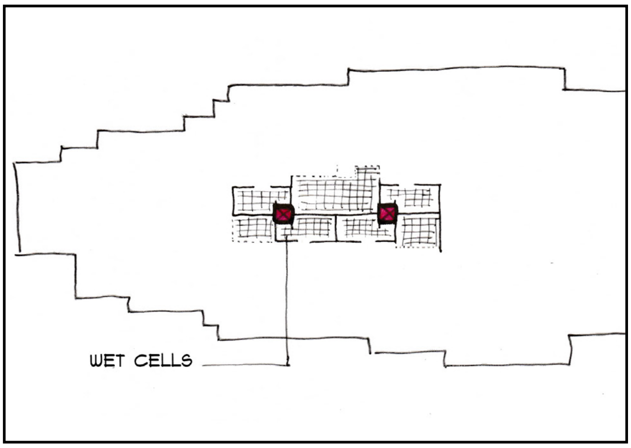
Structure
The structure of the building consist of ‘wandering’ columns which are positioned away from the facade in combination with shear wall stabilization. The columns leaving a lot of freedom. In the floorplan they form a rectangular umbrella. The architects states that placing columns in a fixed grid will support conformidty while irregular ones will stimulate the imagnation. The structure has no clear direction, but offers a flexible layout which makes it possible to create many different floorplans.



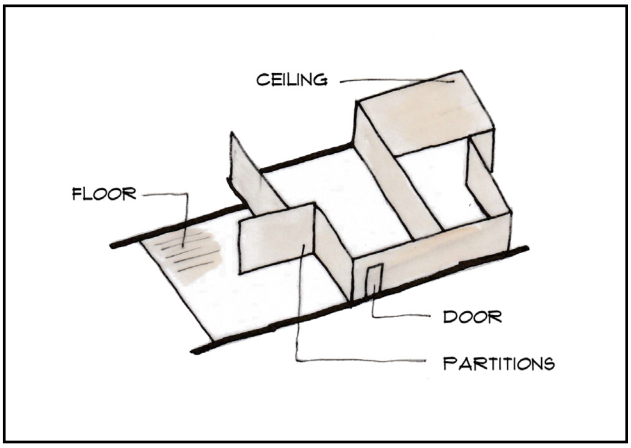
Skin
Facade elements are choosen by the occupants. Everything is placed in a grid of 30cm. This result in a diverse composition of window openings. The curtain wall is demountable so it can be replaced easily. The skin has no clear orientation and the function is unclear by its mixed appearance.



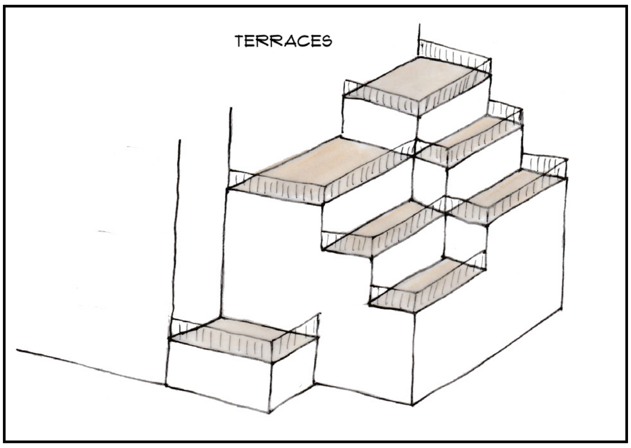
Access
The vertical access elements like the staircases and lifts are placed next to the shearing stabilization walls. The position of these elements are fixed. In contrast to the vertical elements, the horizontal access elements can change. Indoor corridors are formed by the interior partitionswalls. When the size of the units change, the place of the corridors can be addapted.



Servant elements
Two shafts are placed in the center of the building. The studenthouse is made for collective living. All wet-cells like kitchens, bathrooms and toilets are placed in the center around the two shafts. The location of the wet-cells is not flexible. However, it leaves a lot of open and flexible spaces around this central-service area.



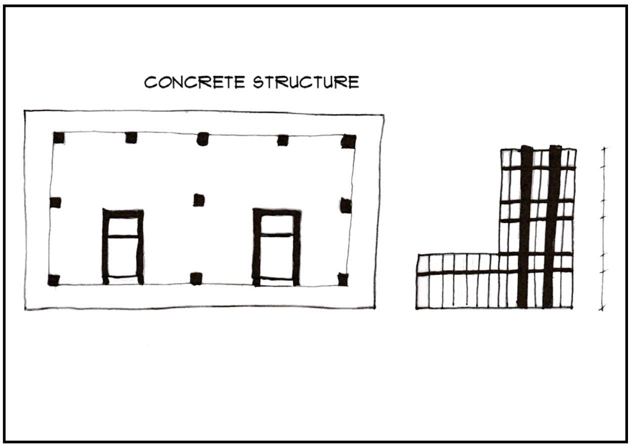
Scenery
Partitionwalls en doors can be installed within the flexible structure. Due to the 'wandering' position of the columns, many diverse floorplan variations are possible. No room will look the same. Larger rooms can be split up easily to accomodate more students in the building. The partition walls are made of gypsum board sheets and a mineral wall core which result in a self-supporting interior wall. The walls are connected to the ceiling with jacks which makes is possible to relocated them without help of a professional.



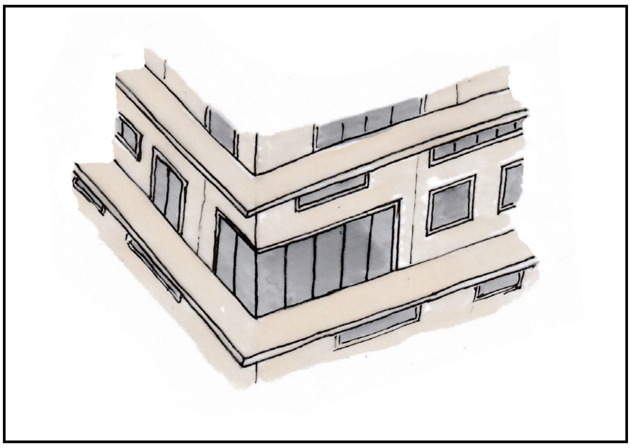
Outdoor space
On the side of the building, collective terraces offer an outdoor space for the students. The terraces are connected with stairs so students can also use them as an escaping route.

Hoge Vrijheid

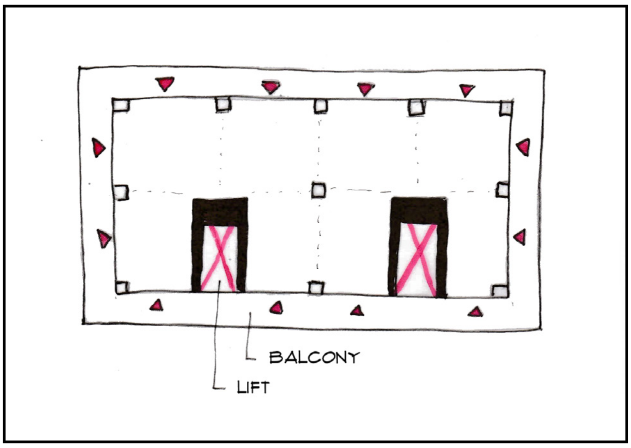
Martijn van der Hijden
Den Haag - 2020



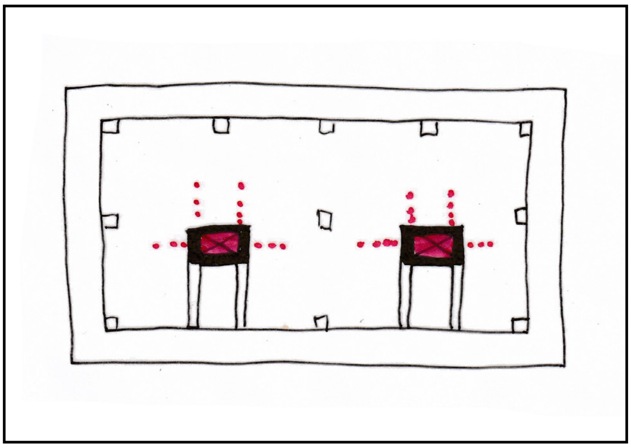
Structure
The structure consist of a grid system with two stabilization cores. The vertical columns, the two cores and the floors are made of concrete. The floor heigts differ and make it possible to make one or two storey units. The columns offer a lot of flexbility and many possibilities for the interior arangement.



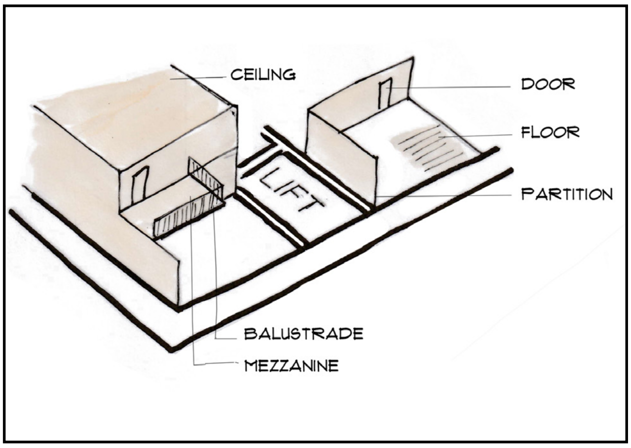
Skin
The skin of the building is quite special. Occupants could choose their facade elements from a catalog. This results in a divers appearance of the facade of each unit. Windows size and heights are different and customized to the needs of the user.



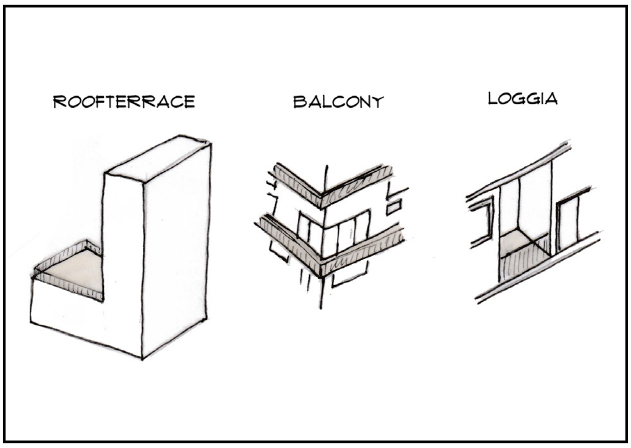
Access
The vertical access elements are located in the two cores. Units can be entered from the outside. An oudoor gallery offers maximum flexibiliiy for the postion and the amount of entrances.



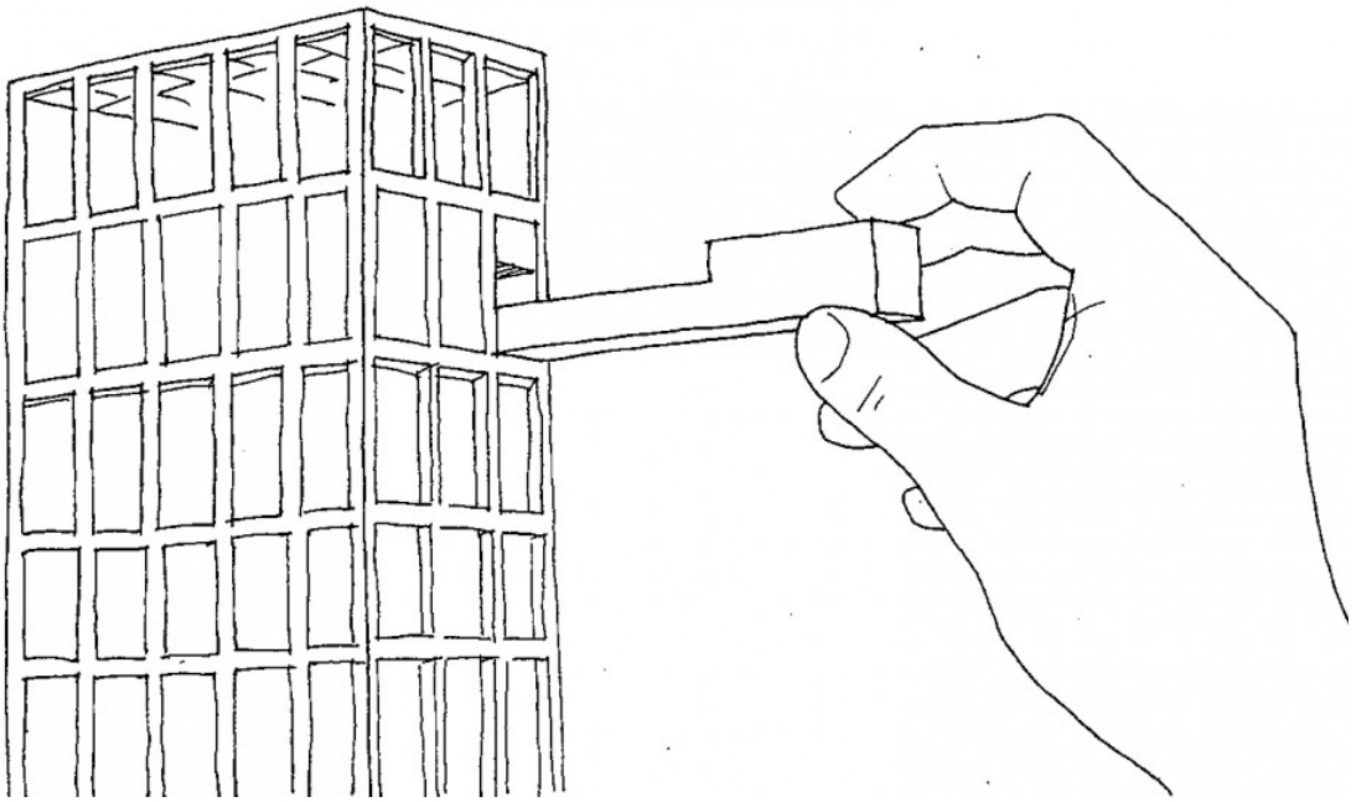
Servant elements
Vertical servant elements are placed in the cores as well. The wet-cells can be connected directly to the servant core since the have a strategic position in the building.



Scenery
Partitions wall and doors can be installed to compartimentize the interior space. The owner can add and adapt floor and ceilings to make the space conform his own requirements. In the double height appartments mezzanines can be added as well.

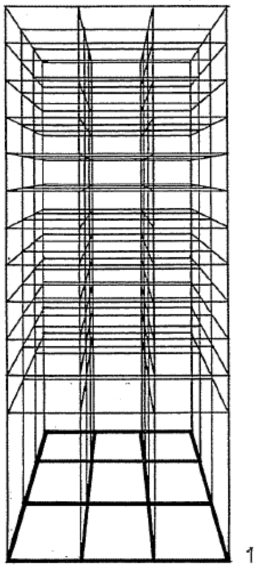


Outdoor space
The building has three types of outdoor space. Roof terraces, balconies and loggia's offer the residents a space where they can enjoy the weather. The collective roof terrace can be used for urban farming, while the balconies and loggia's have a private function.



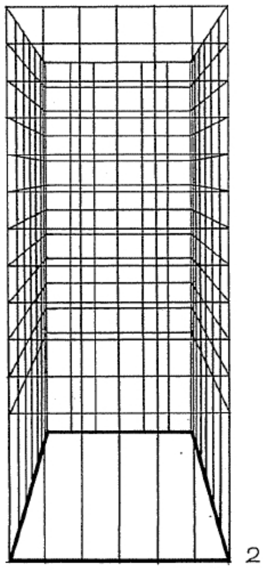
appendix 2
analysis structure with outdoor space

Structure types



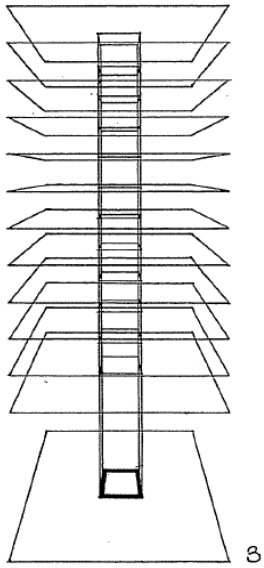
grid highrises

Loads are evenly distrib-
uted over the floorplan



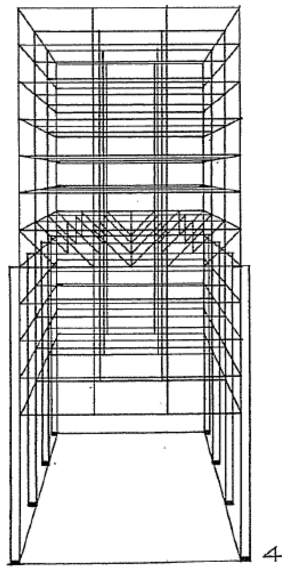
casing highrises

Loads collection zone is arranged peripherally



core highrises

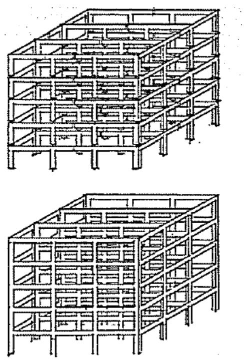
Load collection zone in the core which is centrally located



bridge highrises

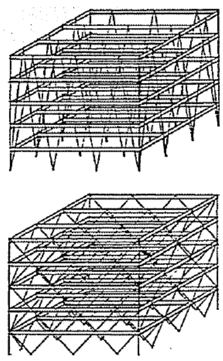
Loads are directed to a super imposed seperated structure

(Engel, 1997)



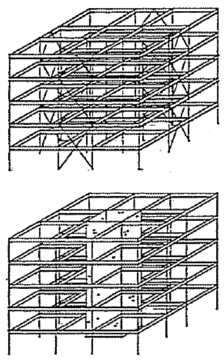
framed bays

- stacked hinged frames
- all-bay through-frames



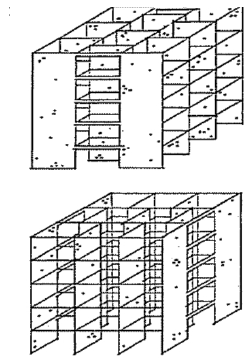
trussed bays

- trusses along one floor
-trusses along multiple floors



stabilized post-beam bays

- single bay bracing
- core stabilization / shear wall stabilization



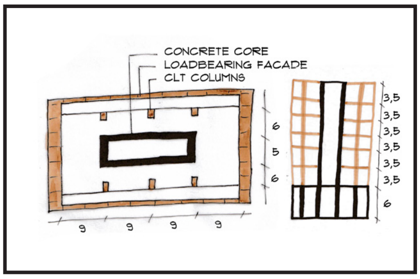
shear walls

- longitudinal walls-
- crosswall- / two-way wall systems

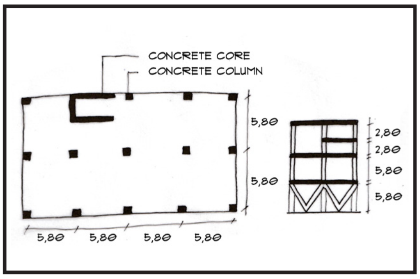
(Engel, 1997)

Structures Open Building

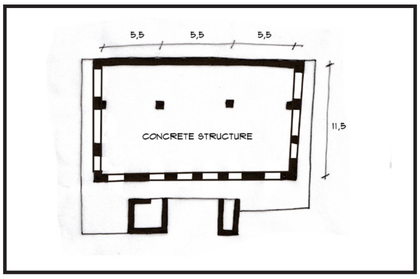
All analysed open building structures consist of a grid system. Most of them are stabilized with a core which is in all cases made of concrete.



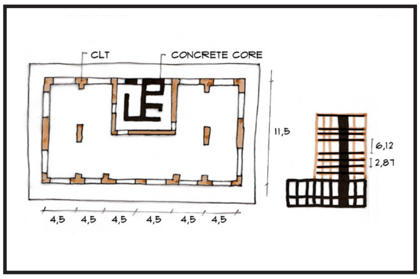
grid system: core stabilisation and shear walls



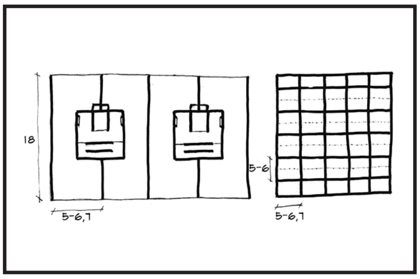
grid system: single bay bracing and shear wall stabilisation



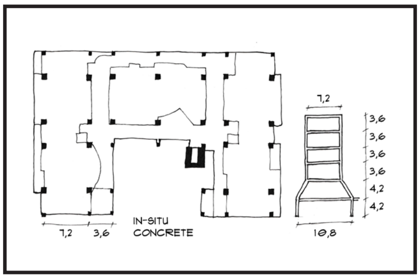
grid system: two-way wall system (almost shear wall casing)



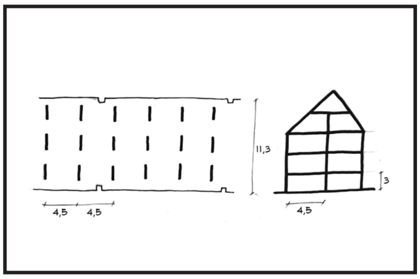
grid system: core stabilisation and two-way wallsystem with cut-outs



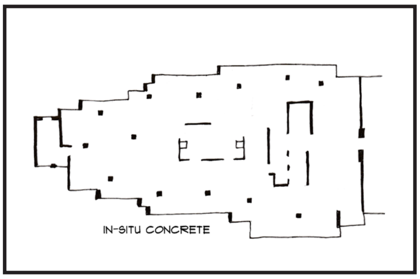
grid system: longitudinal wall system



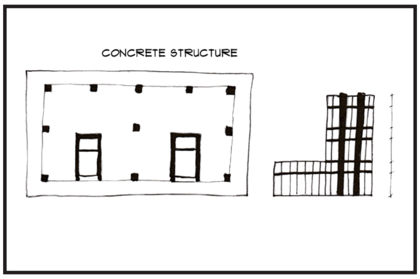
grid system: framed bays



grid system: longitudinal wall system



grid system: shear wall stabilization



grid system: core stabilization

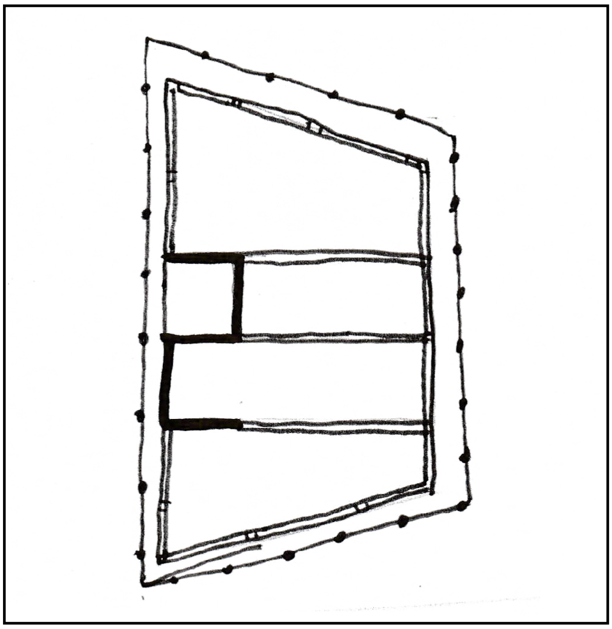
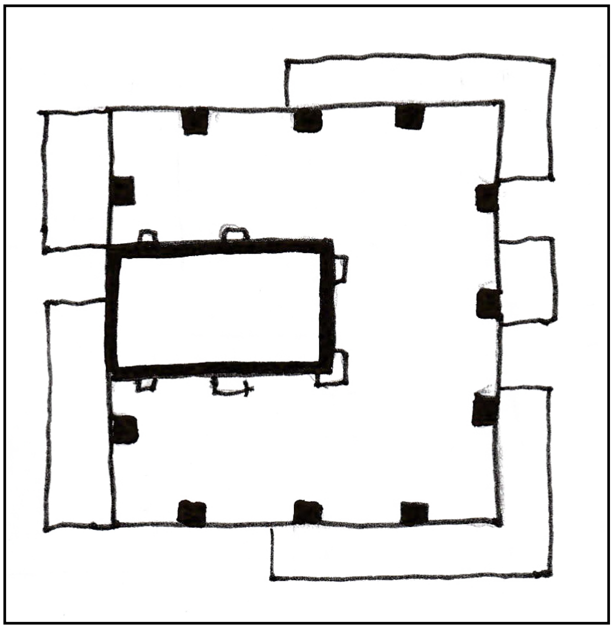
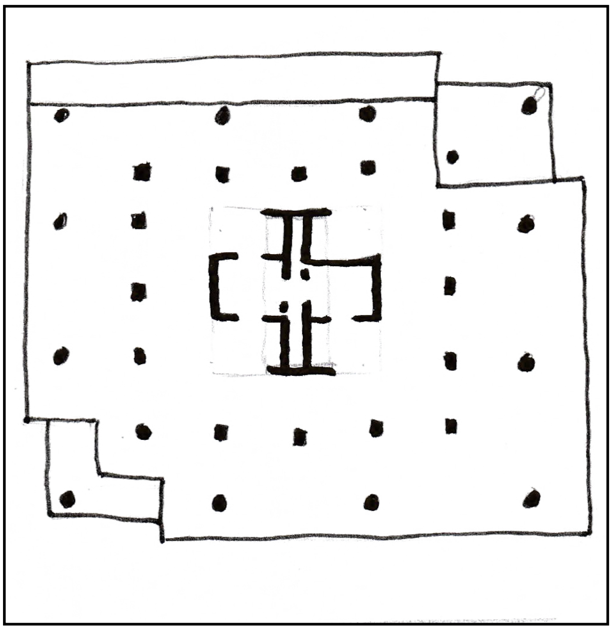
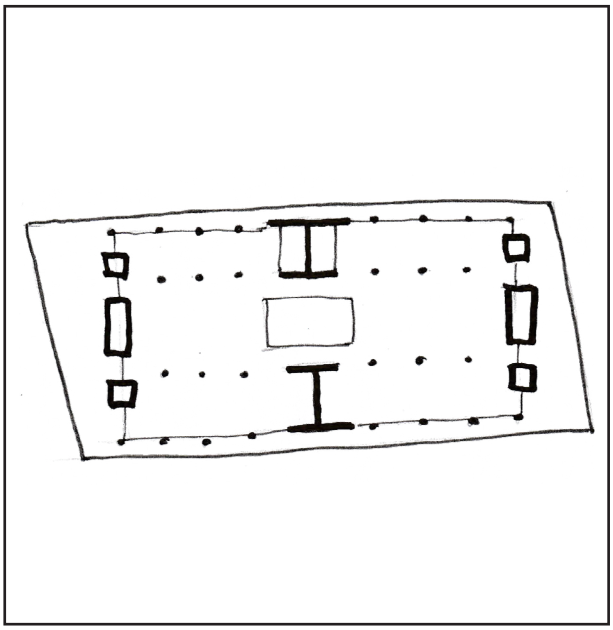
Flexible structures <150m

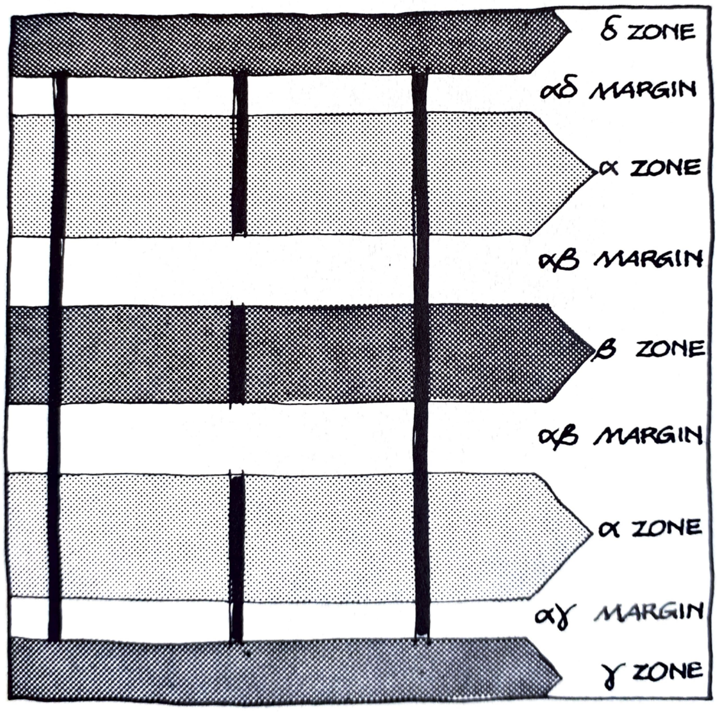
Sou Fujimoto - Laisné Roussel

Stefano Boeri - Bosco Verticale

Herzog de Meuron - Beirut Terraces

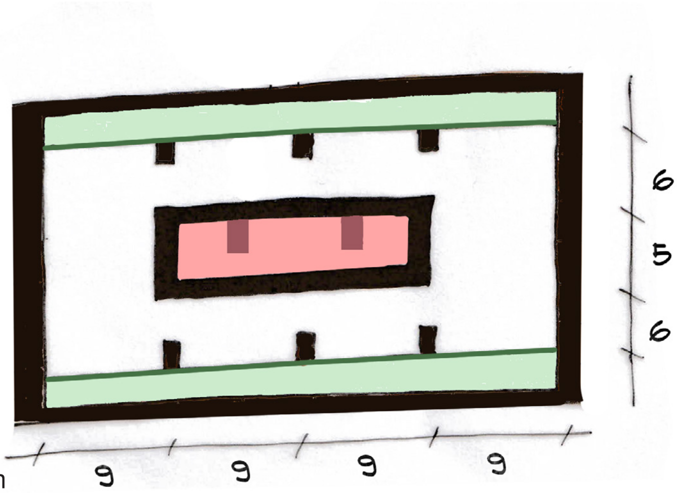
Nicolas Laisné Architects - Nice Meridia



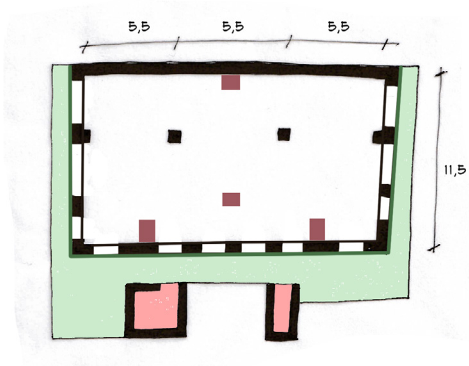
appendix 3
zoning open building case studies

Support zoning open buildings



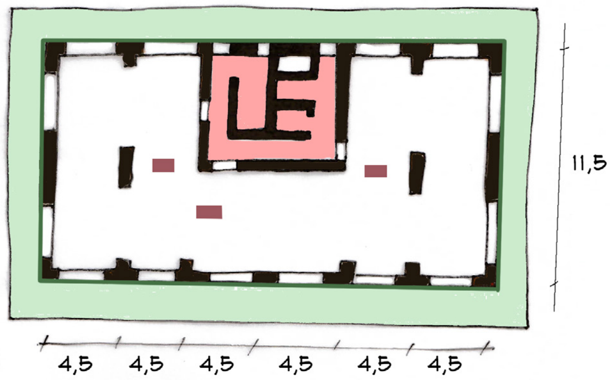
Patch 22 (2016)
Frantzen et. al - Amsterdam

Object One (concept)
Space & Matter - Deventer

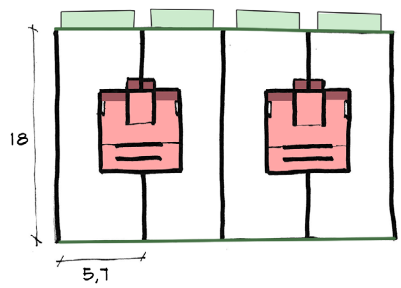


CiWoCo (2019)
GAAGA - Amsterdam

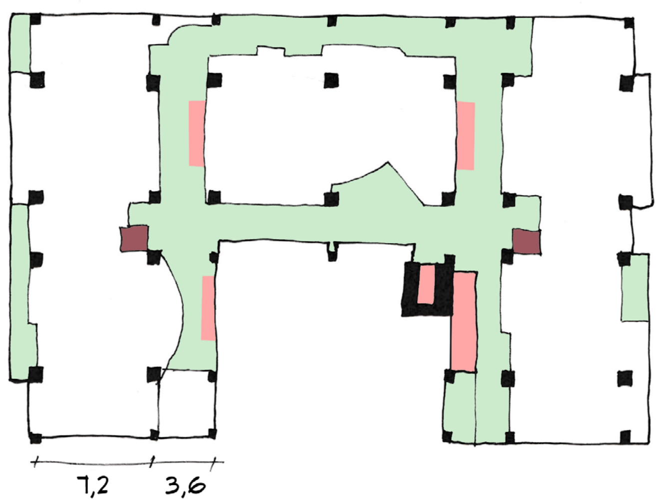
- vertical access
- vertical services
- outdoor space



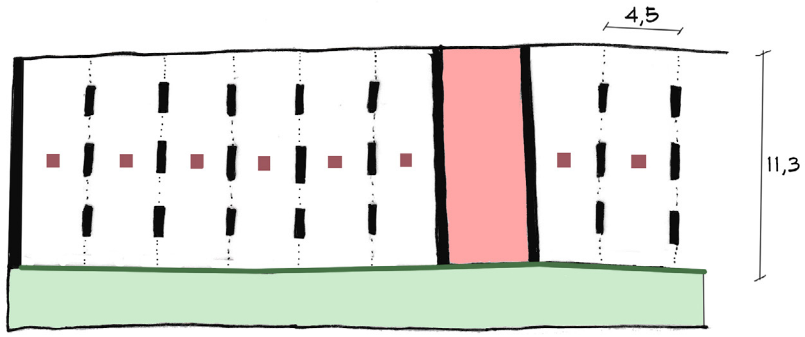
Stories (2020)
Olaf Gipser - Amsterdam



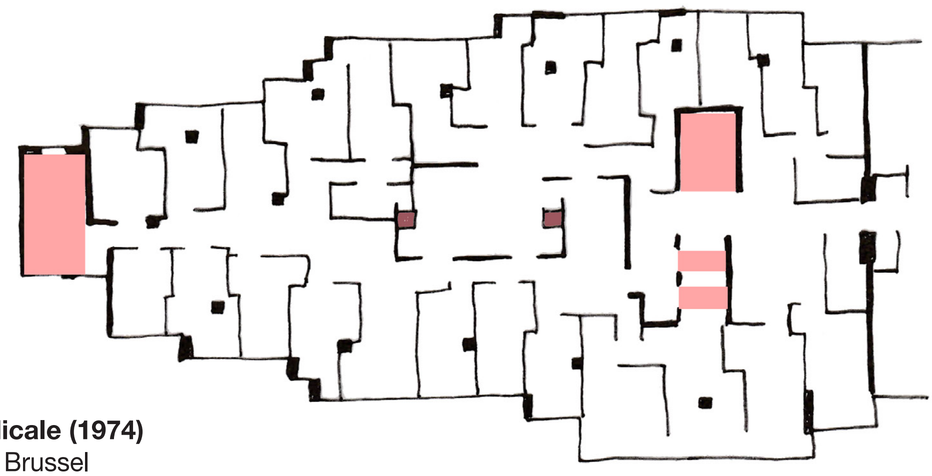
Superlofts Houthavens (2016)
Marc Koehler - Amsterdam



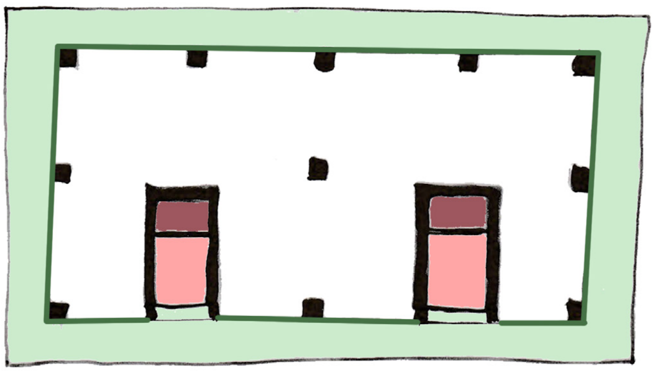
Next 21 (1994)
Yositika Utida - Osaka



Molenvliet (1978)
Frans van der Werf - Papendrecht



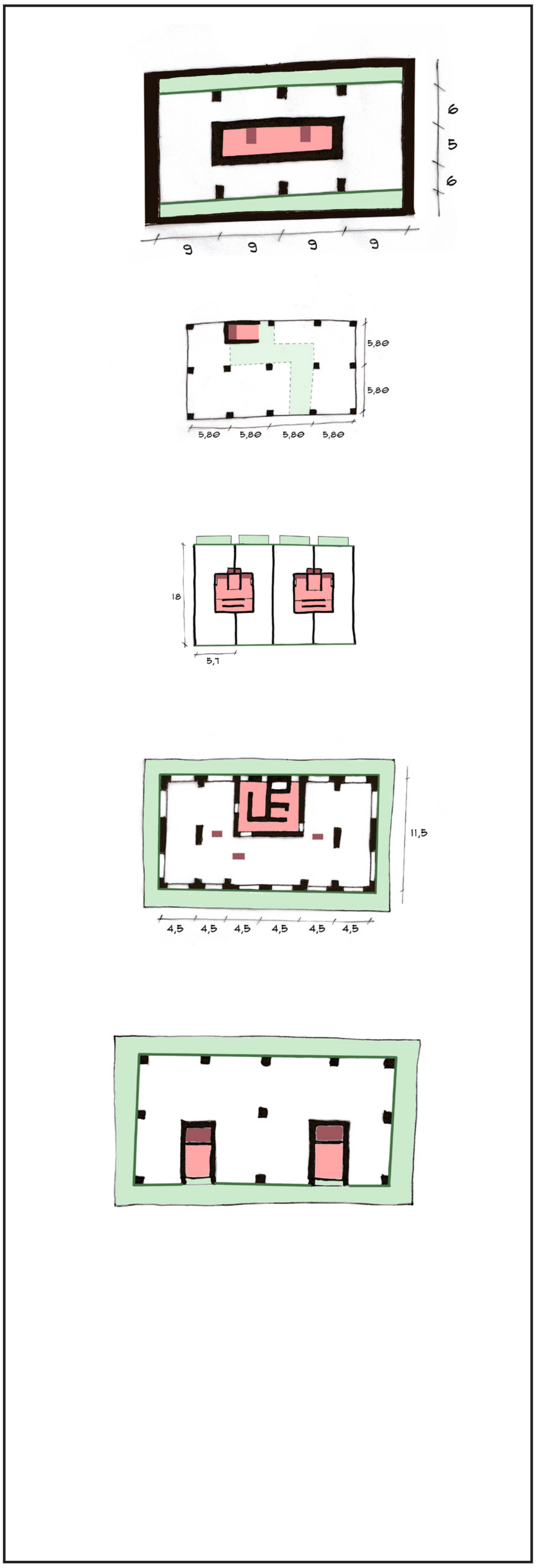
Maison Medicale (1974)
Lucien Kroll - Brussel



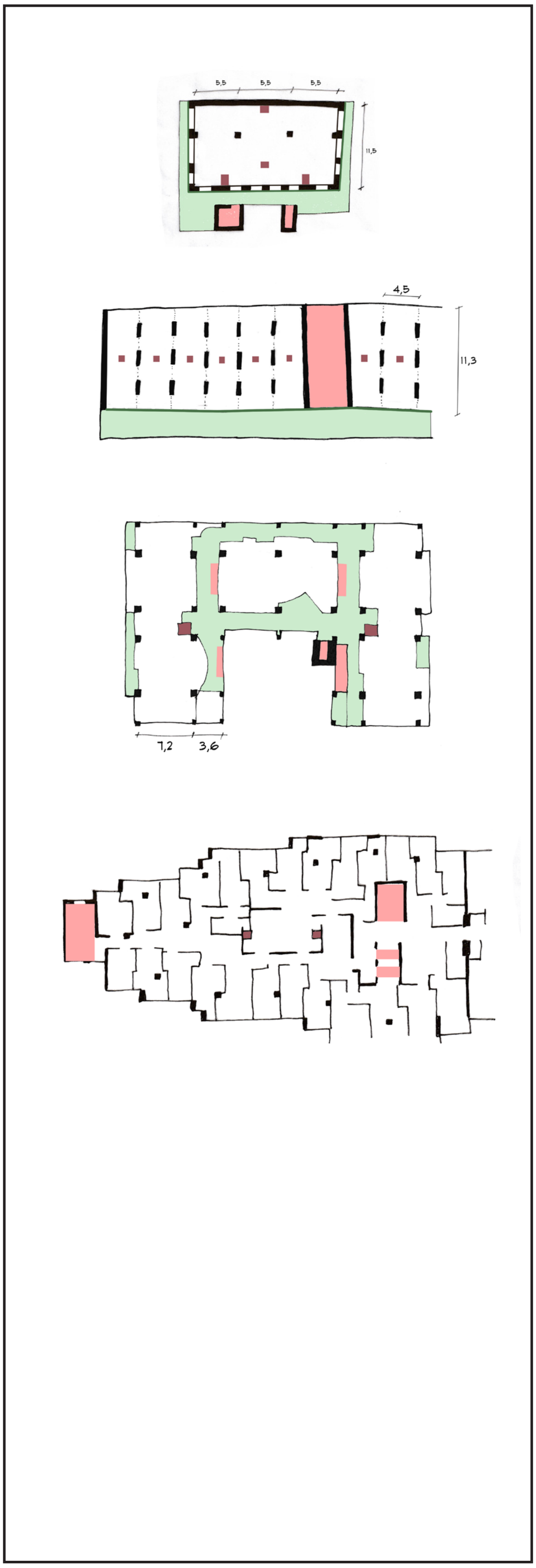
Hoge Vrijheid (2020)
Martijn van der Hijden - Den Haag

structure stabilization

core stabilization

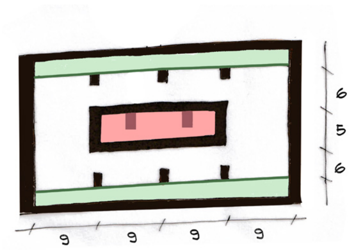


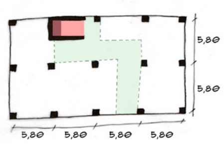
no core stabilization

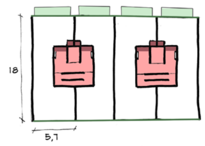


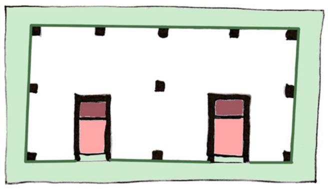
access vertical

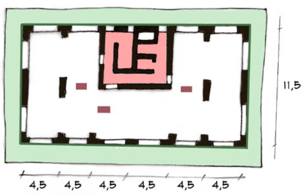
inside core



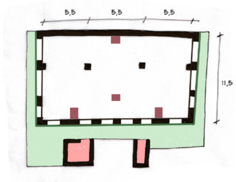


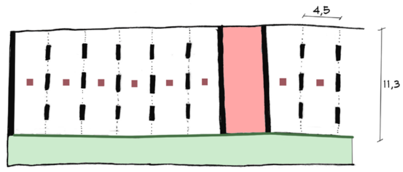


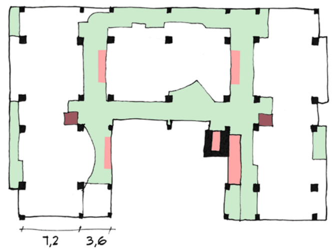


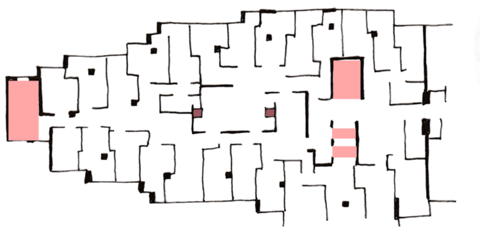


outside core



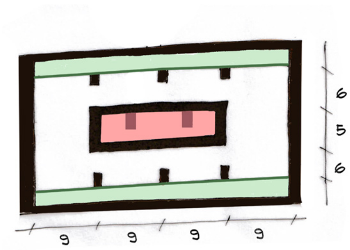


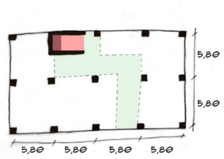


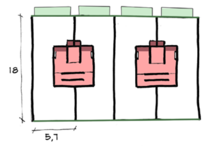


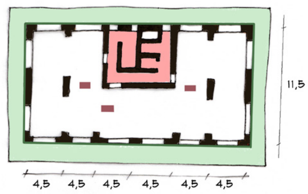
access unit

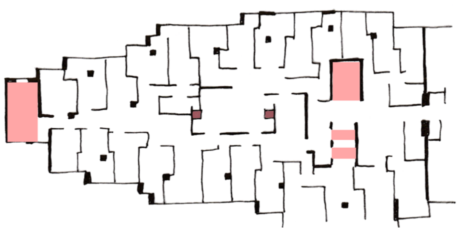
inside



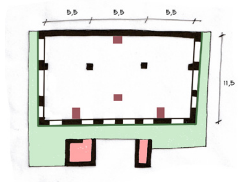


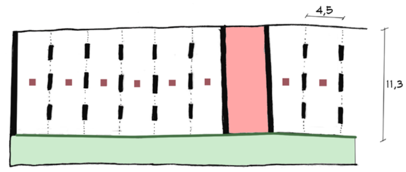


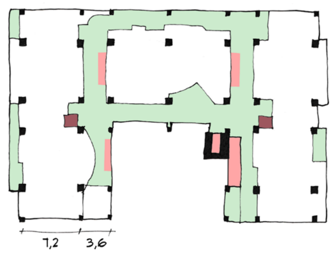


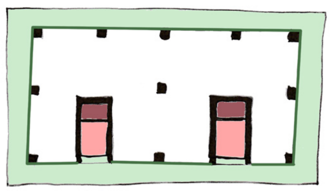


outside



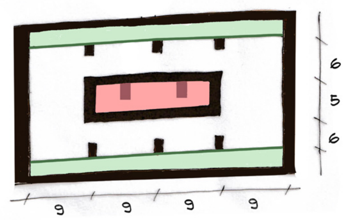


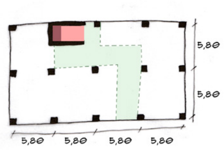


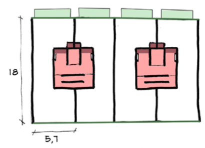


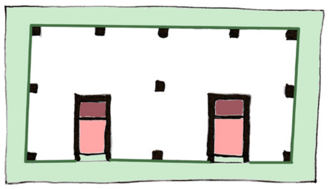
vertical services

inside core

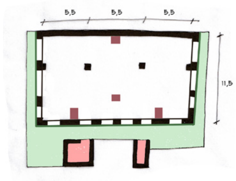


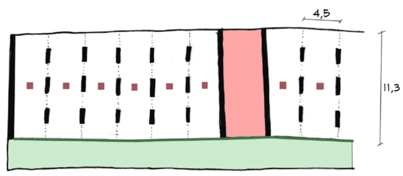


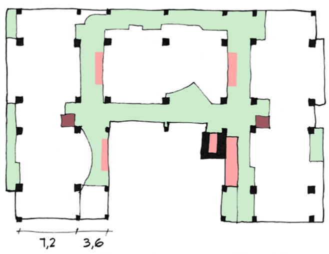


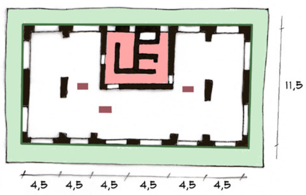


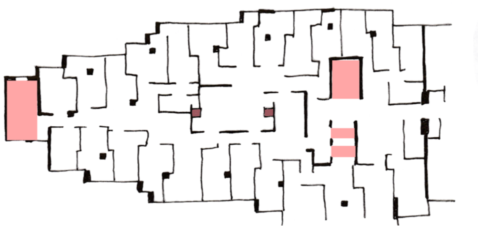
outside core





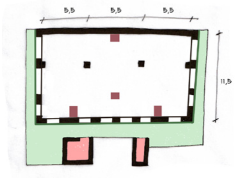


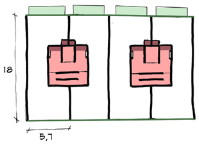


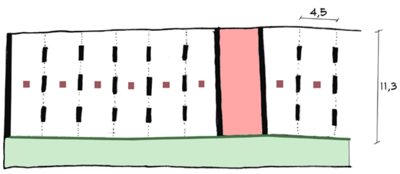


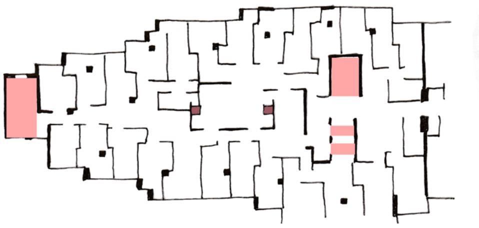
services location wet-cells

fixed position wet-cells

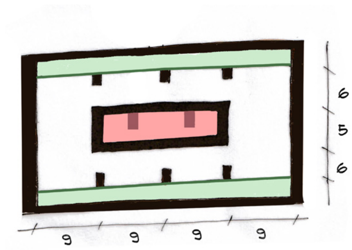


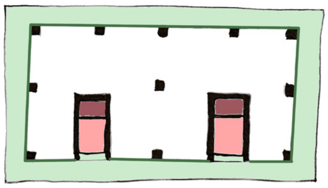


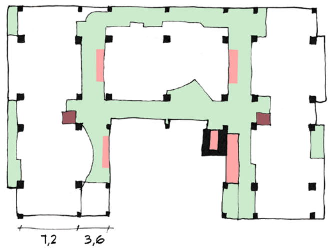


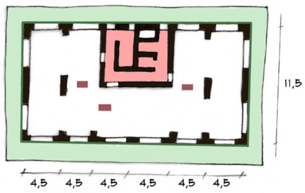


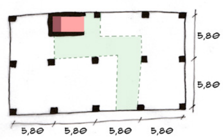
flexible postion wet-cells





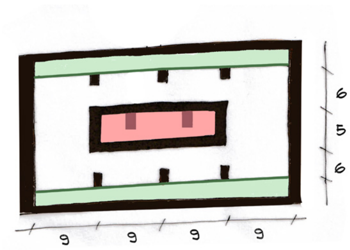


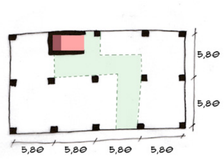


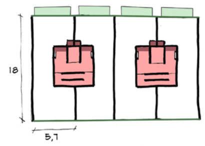


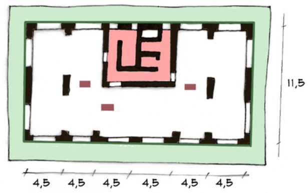
outdoor space type

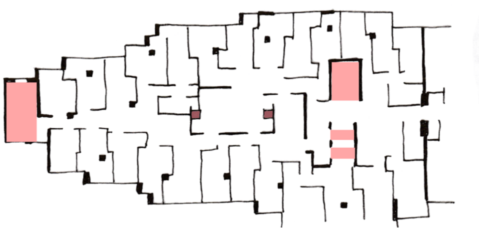
separated / private outdoor space



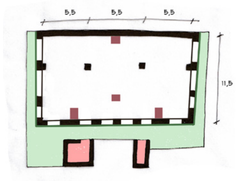


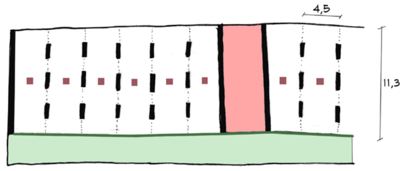


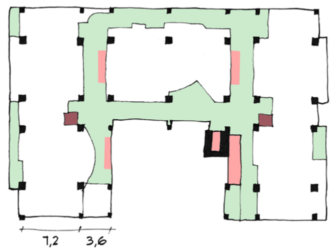


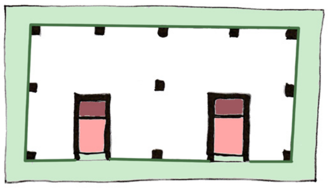


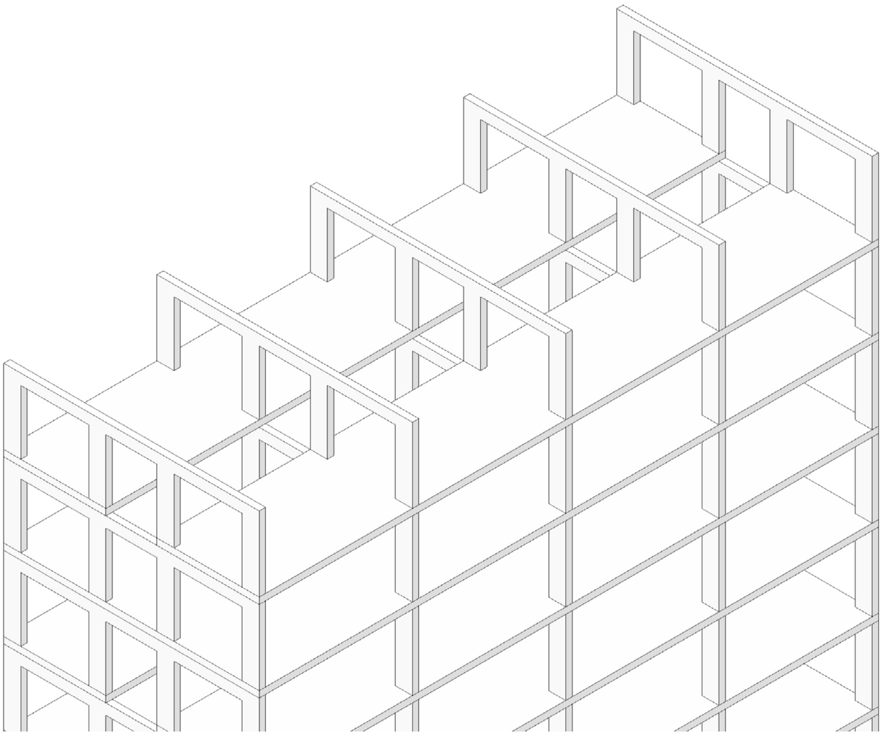
(collective) streets in the sky





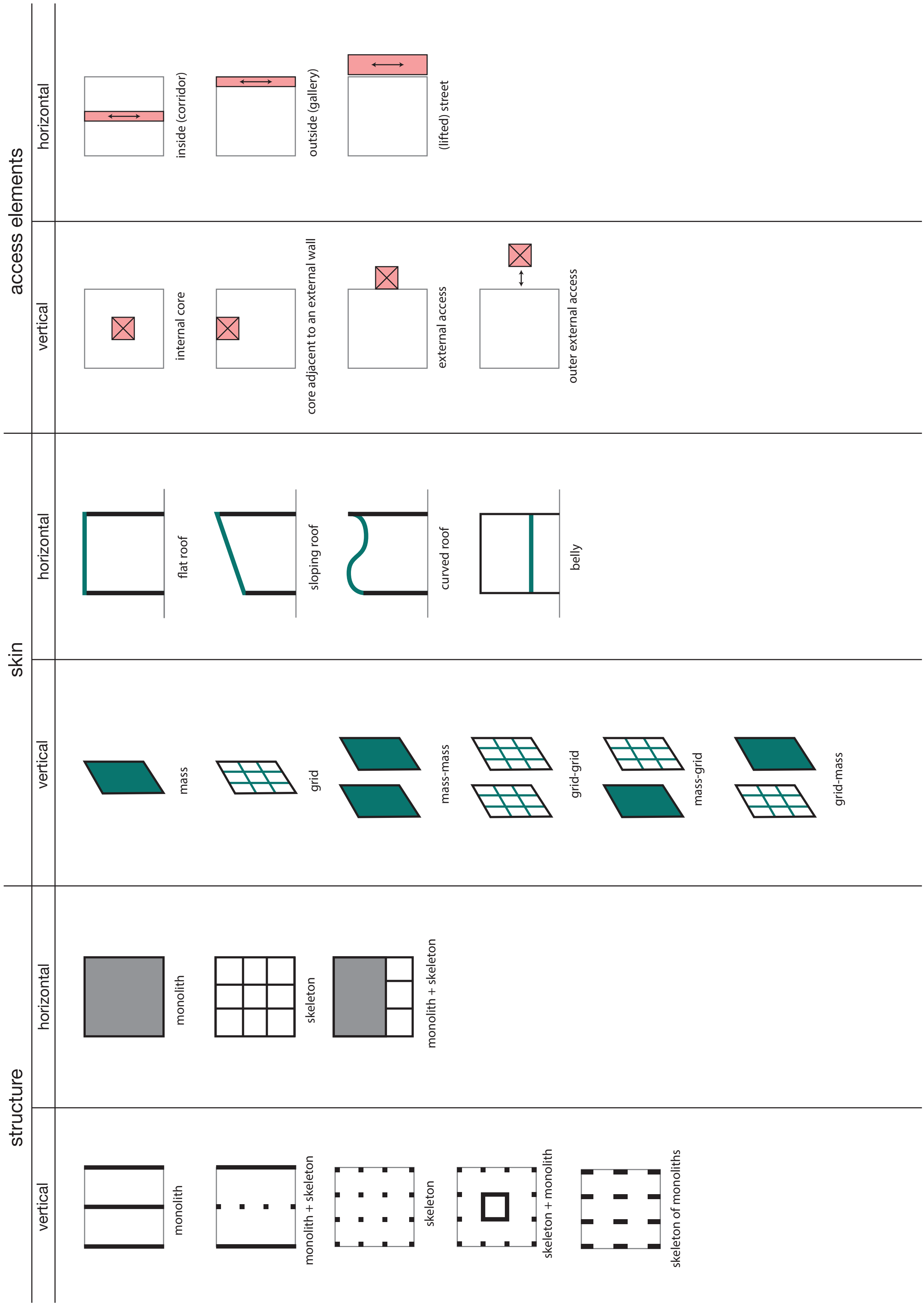


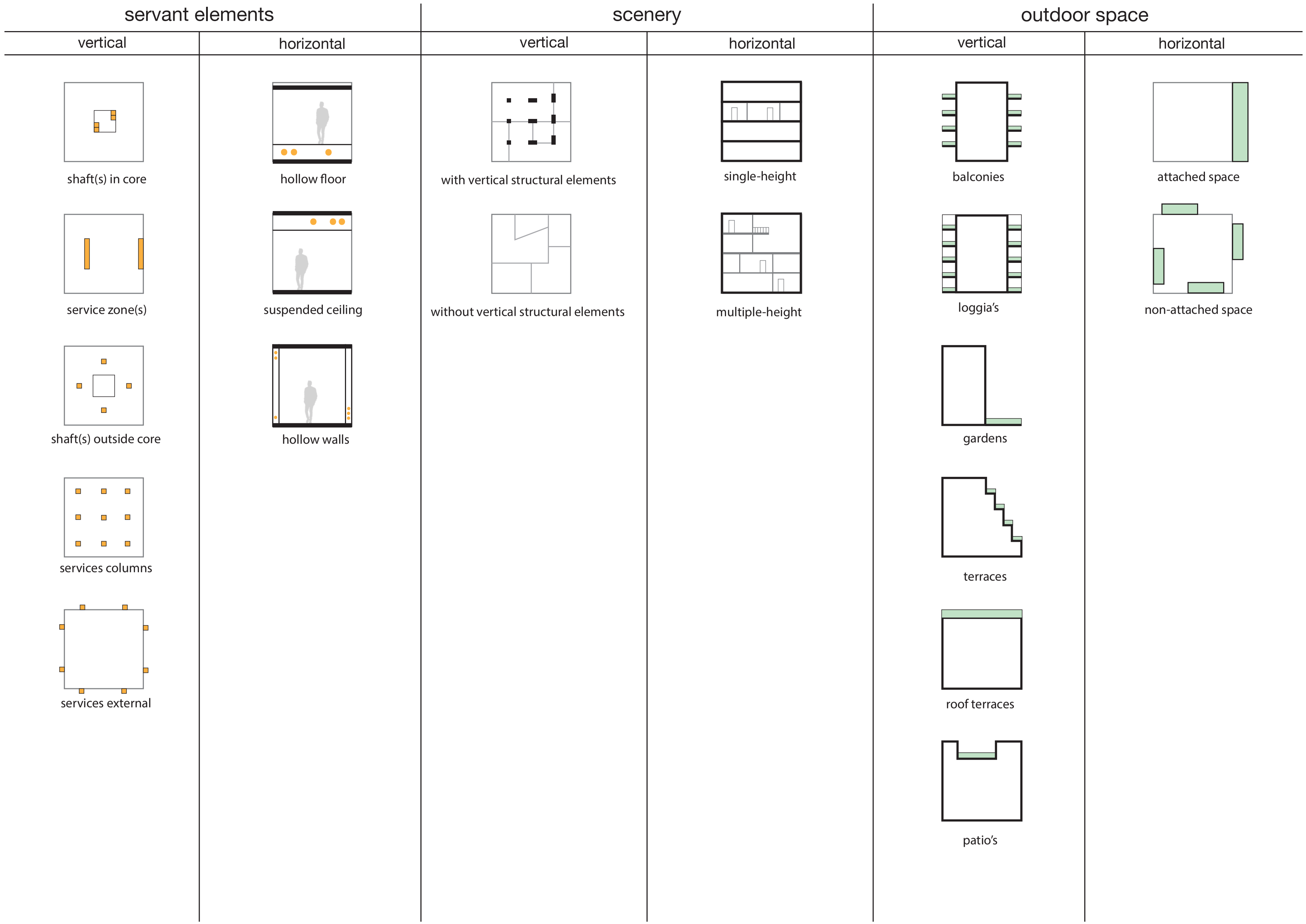




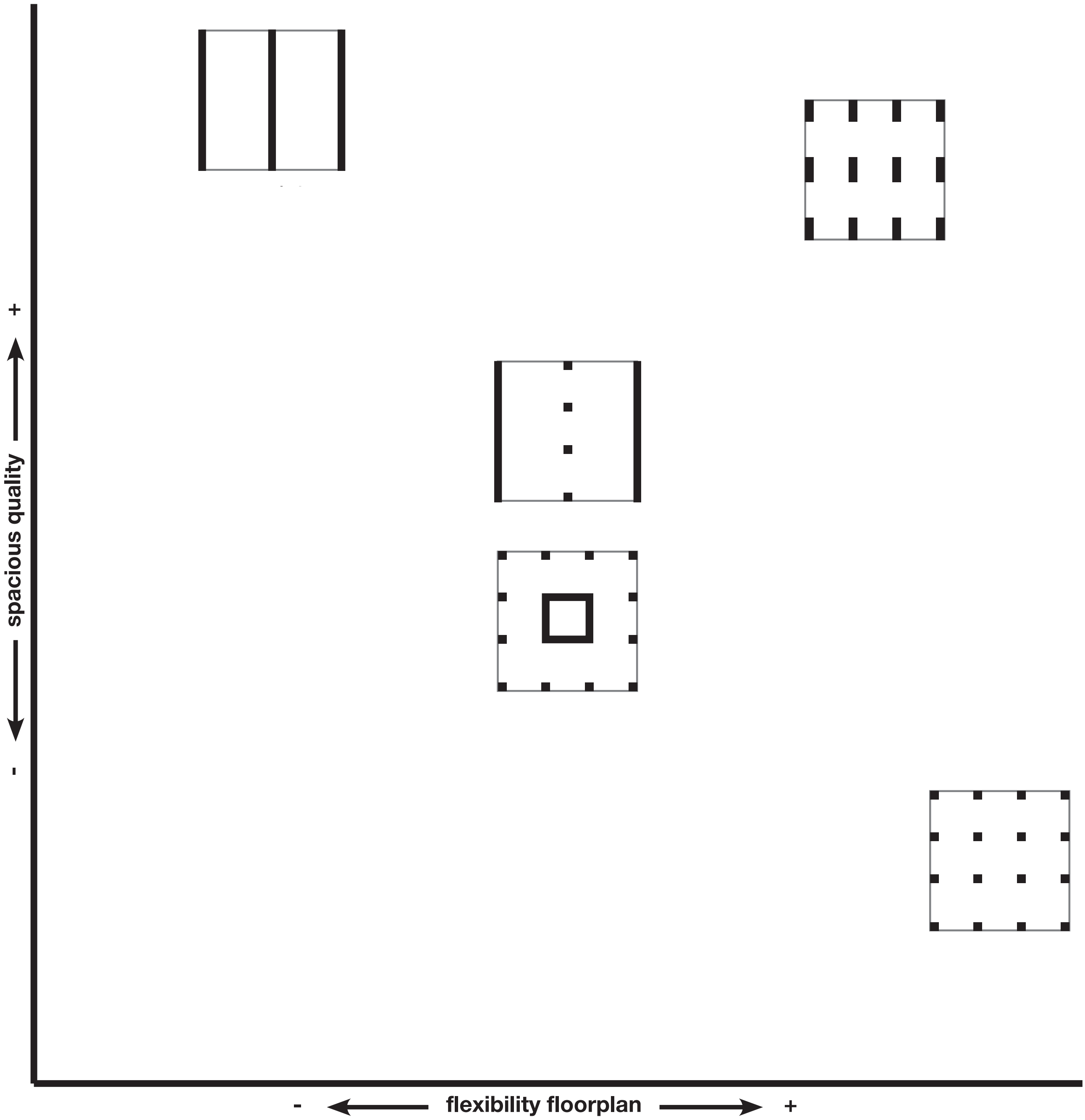
appendix 4
layer types and zoning supports

layers and zoning supports

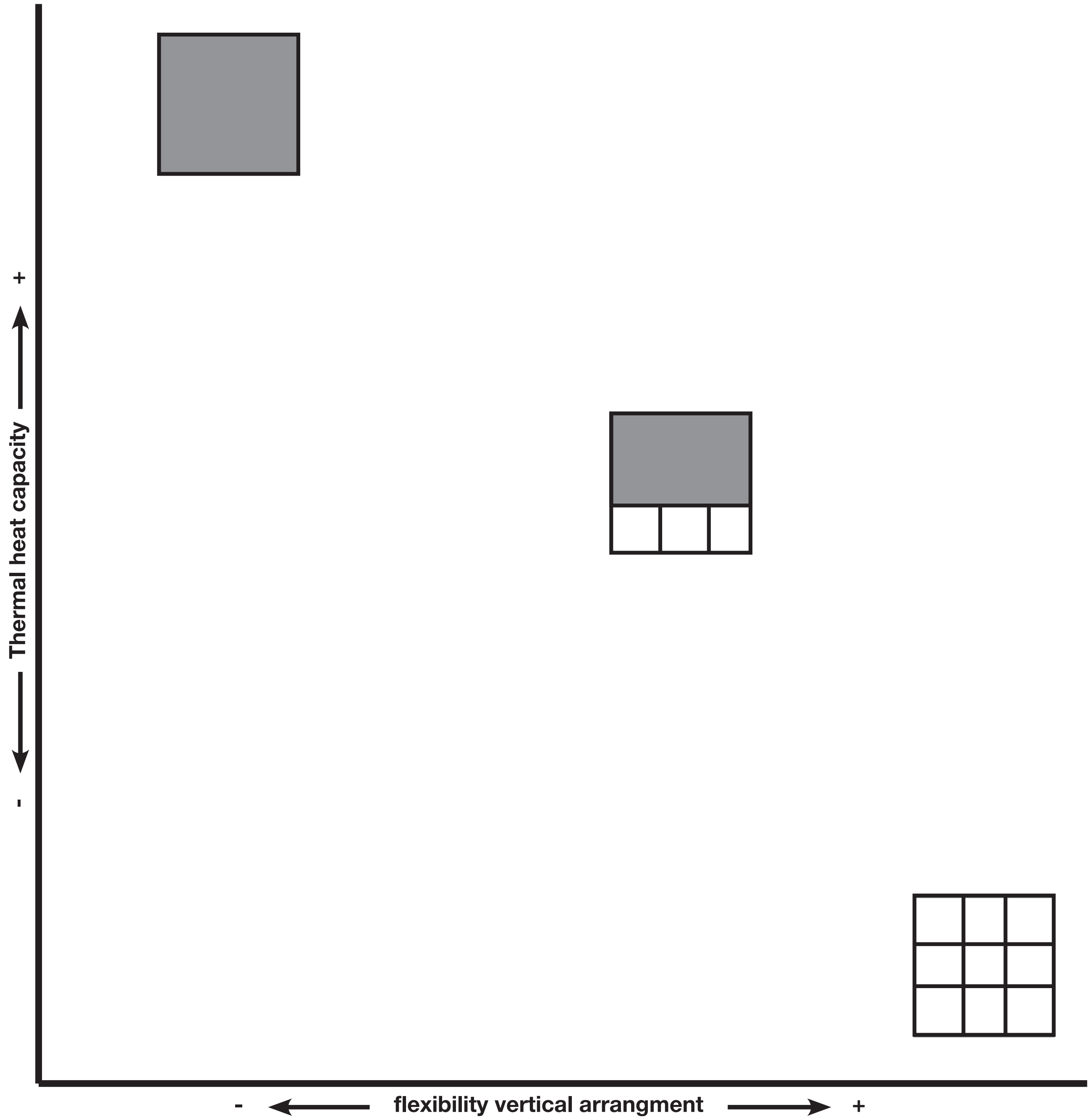



servant elements
vertical
horizontal
scenery
vertical
horizontal
outdoor space
vertical
horizontal
shaft(s) in core
service zone(s)
shaft(s) outside core
services columns
services external
hollow floor
suspended ceiling
hollow walls
with vertical structural elements
without vertical structural elements
single-height
multiple-height
balconies
loggia's
gardens
terraces
roof terraces
patio's
attached space
non-attached space

structure

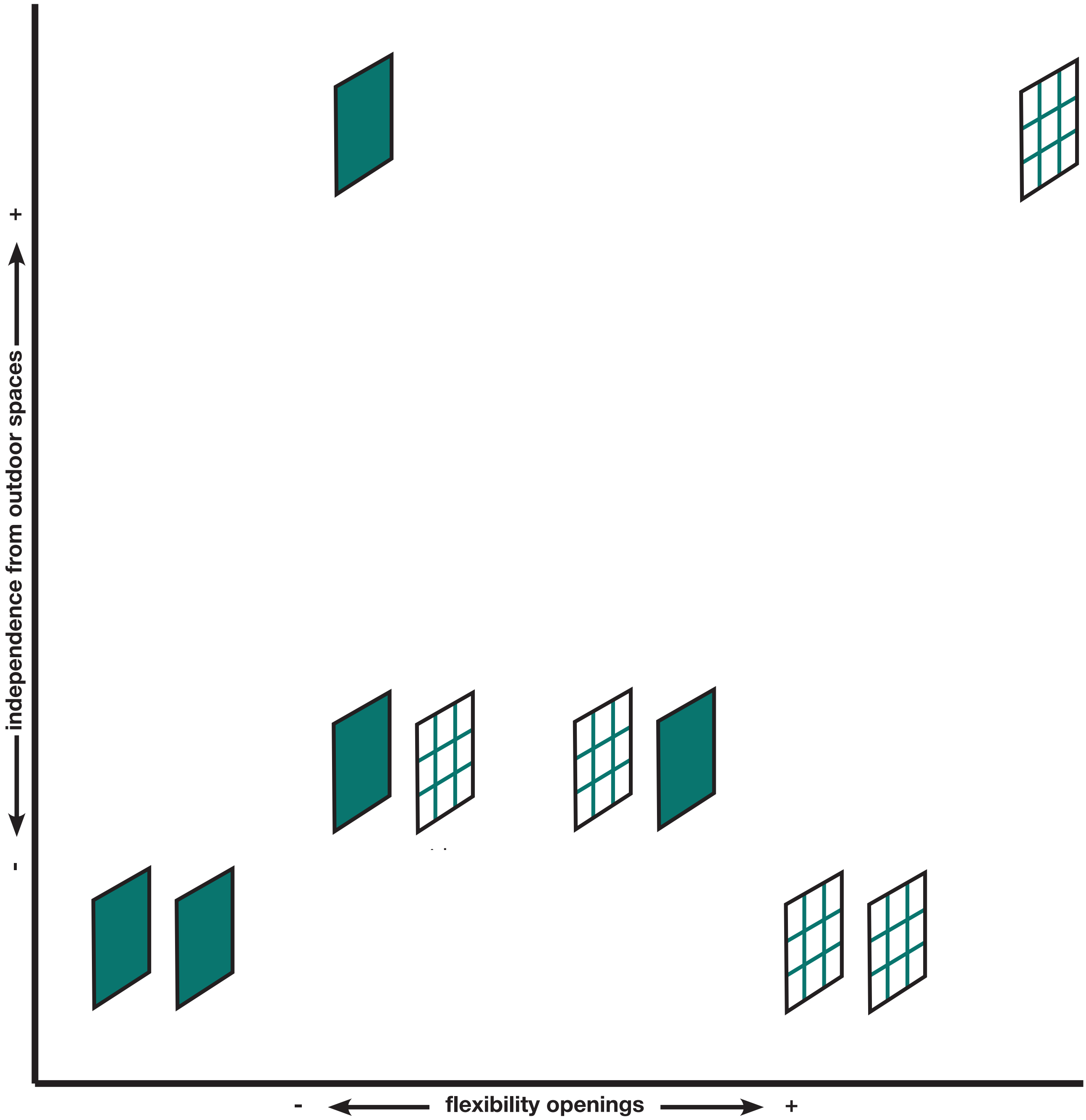


1. The structure is flexible and open for multiple types of layouts
2. The structure has spacious qualities; columns tend to be more neutral and have less spacious meaning

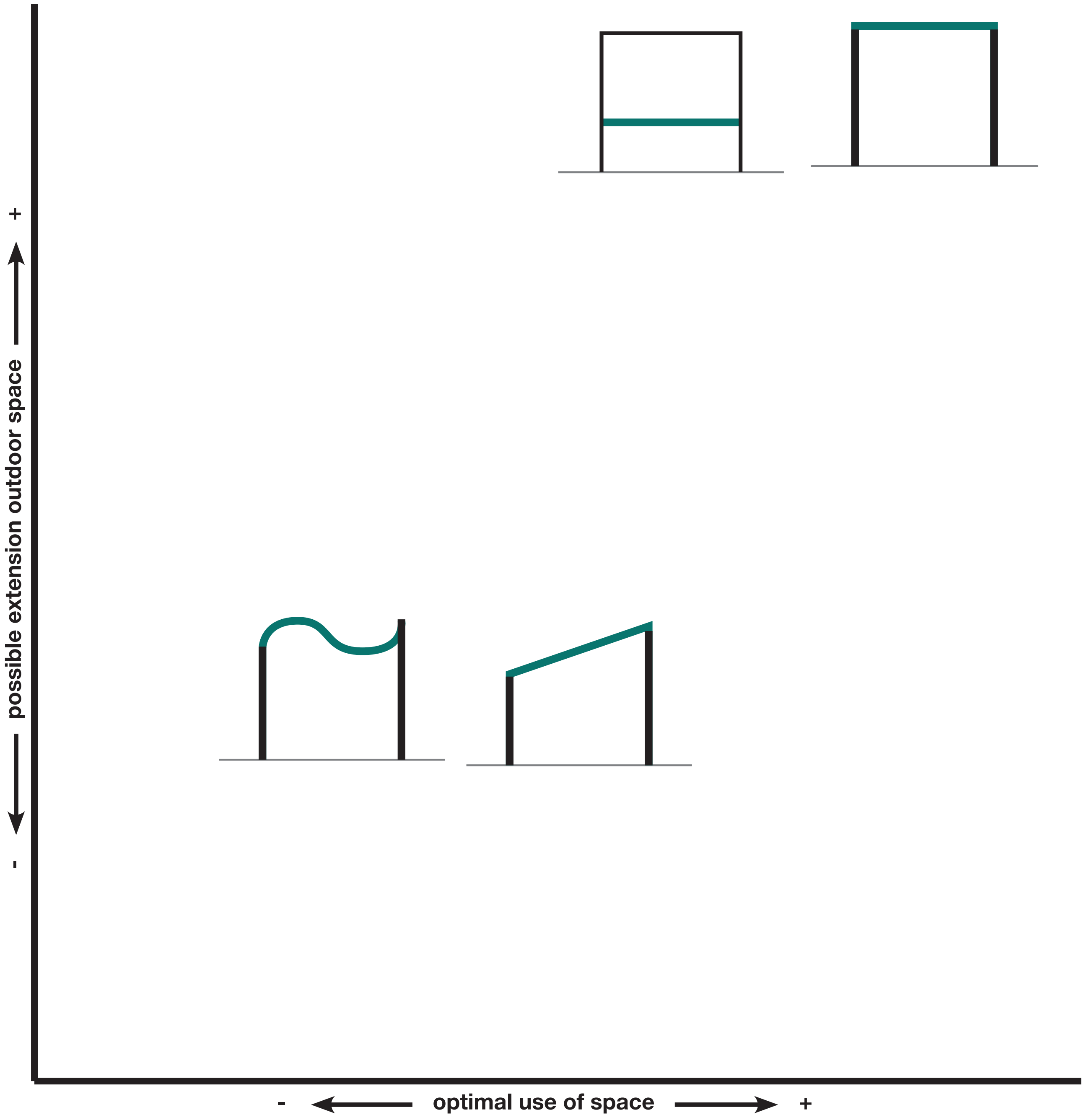


1. The structure is flexible and open for vertical arrangements of one or multiple units
2. The structure has a high thermal heat capacity which will make the building more energy efficient

skin

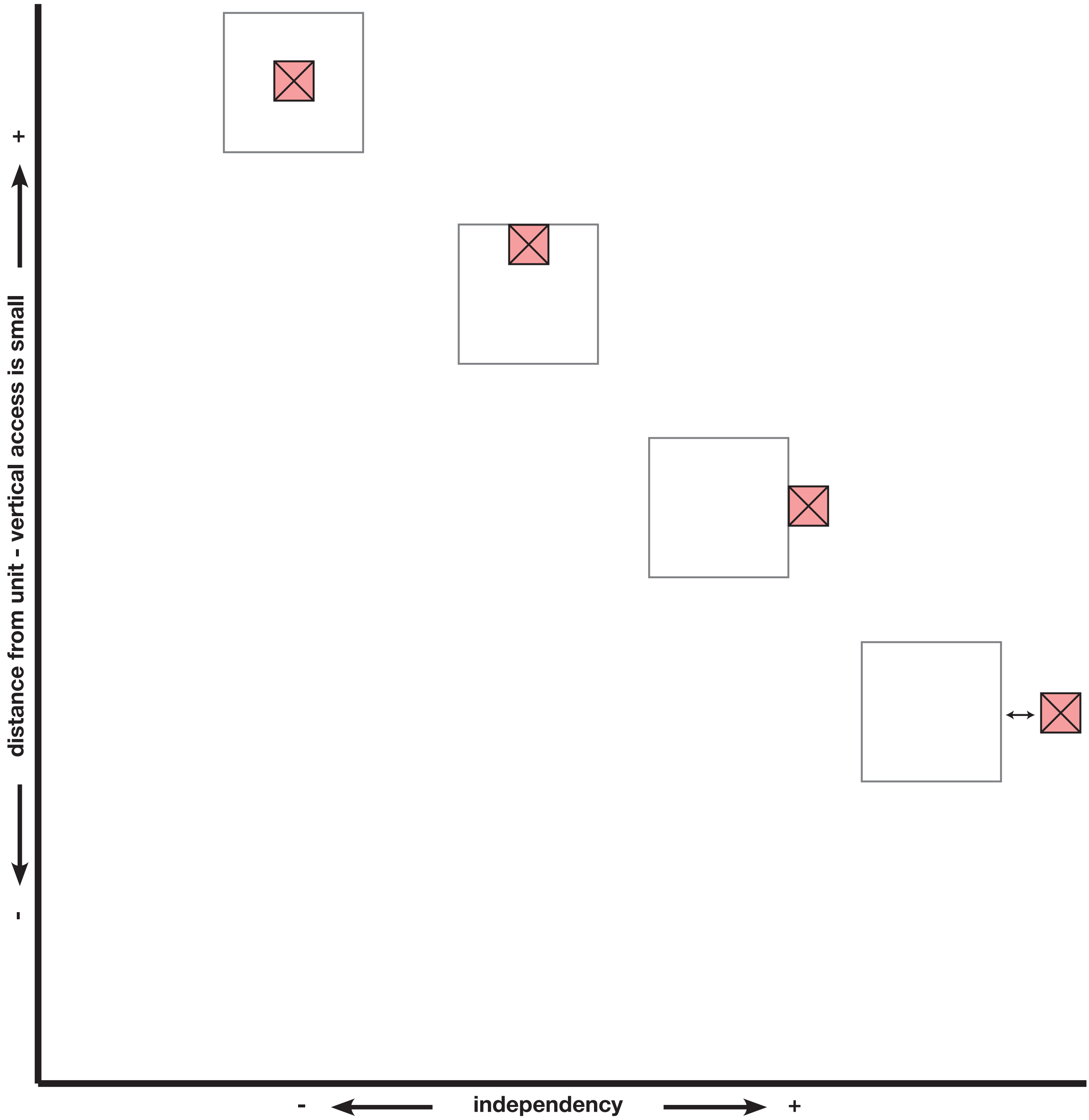


1. Openings in the skin can be changed due to its flexibility
2. The interference with outdoor spaces is minimalized



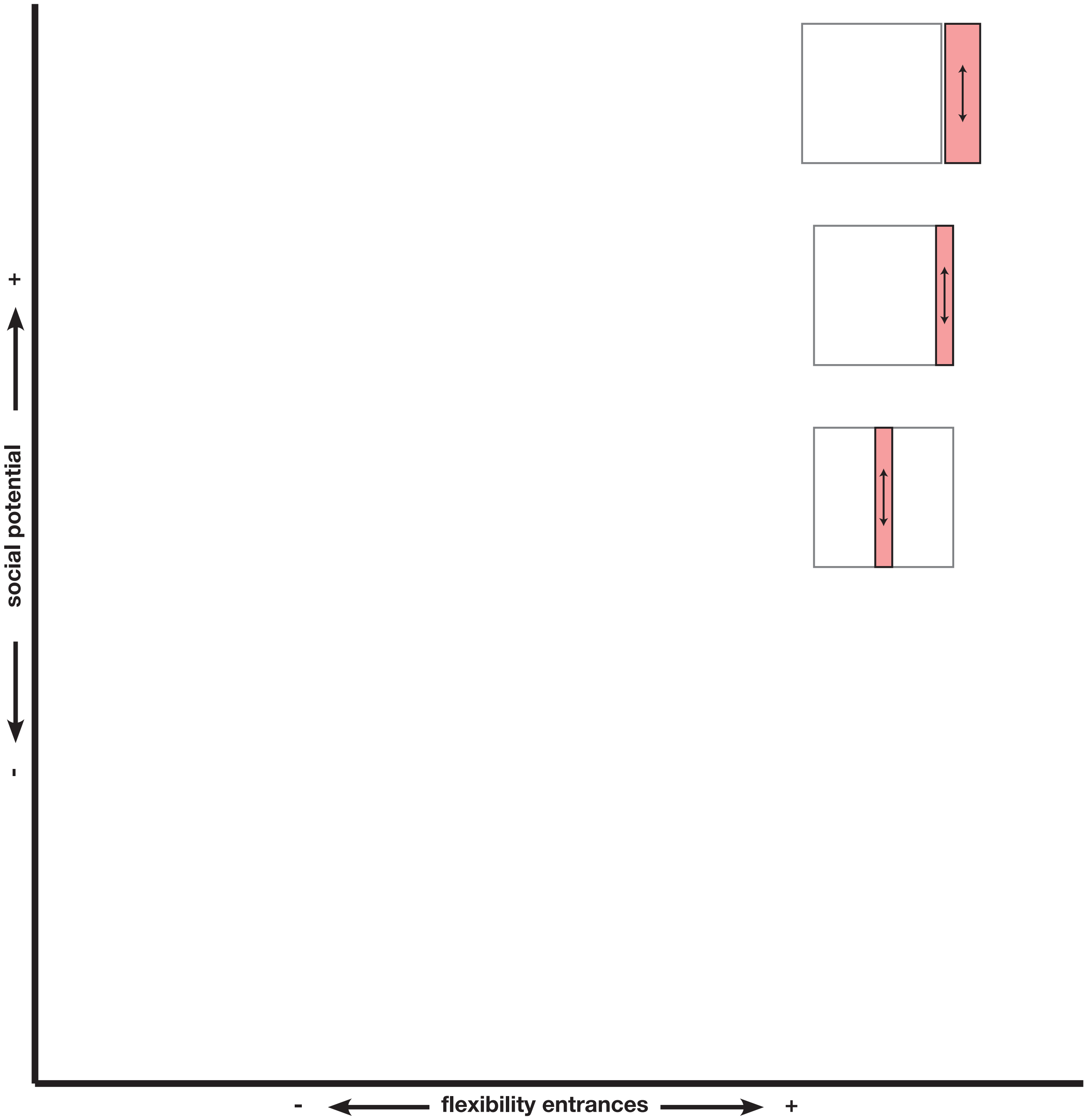
1. The skin provides an optimal use of space
2. The horizontal elements of the skin can provide an extension of the outdoor space

access



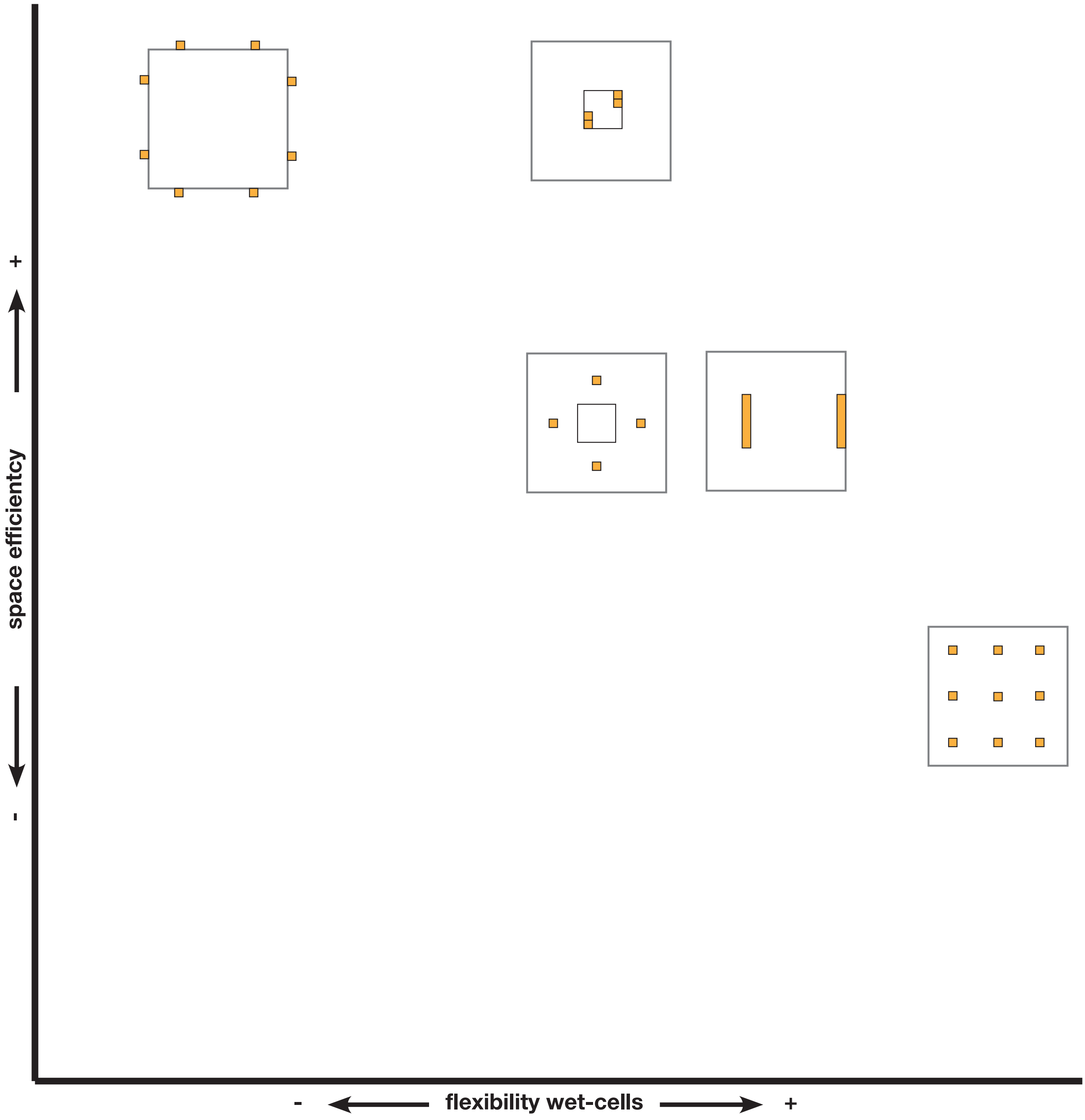
x

1. The vertical access is independent from the structure
2. The distance from a unit to a vertical access element is small

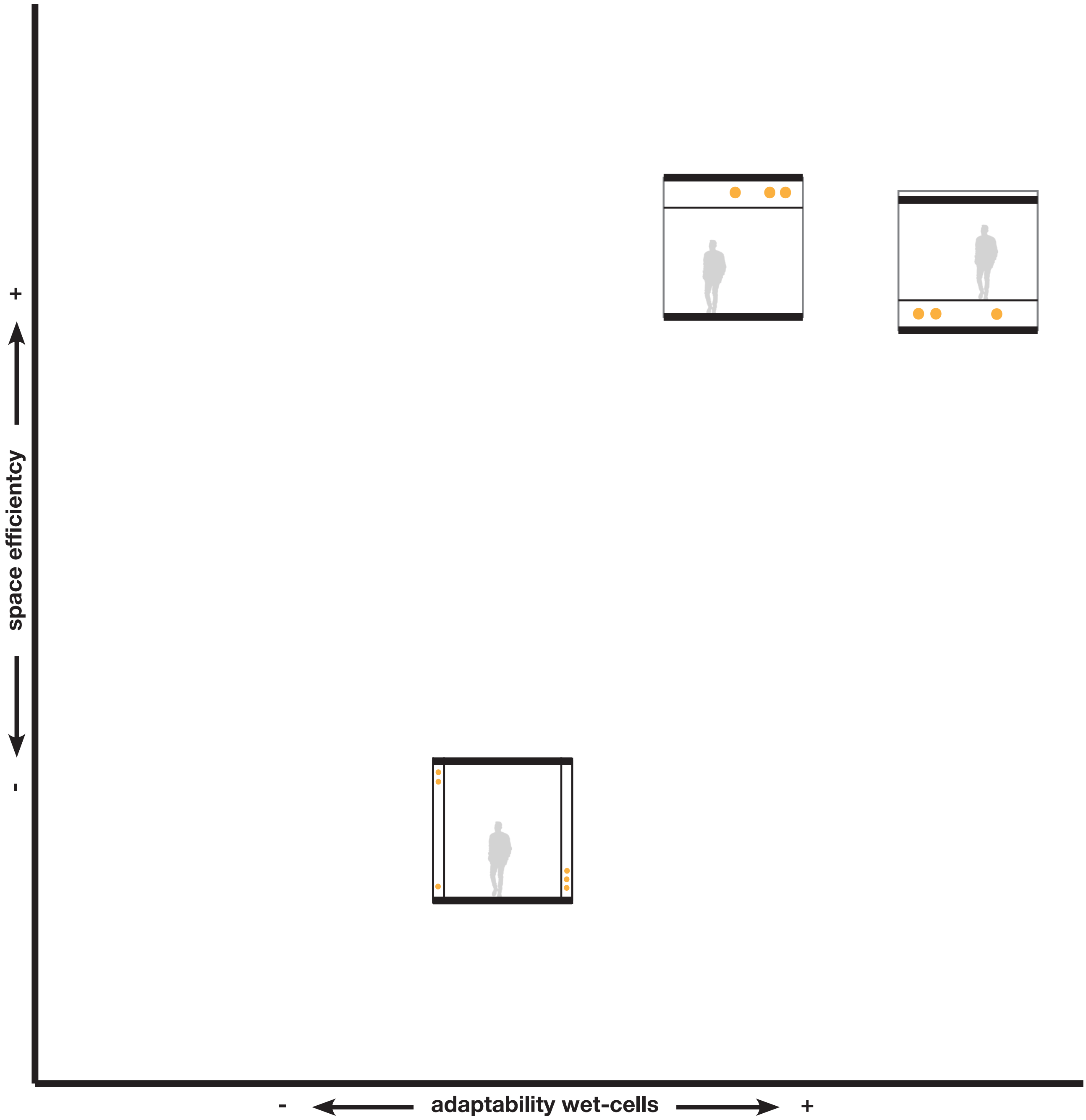


1. Additional entrances can be added later due to flexible horizontal access spaces
2. The access spaces have a potential social character

services

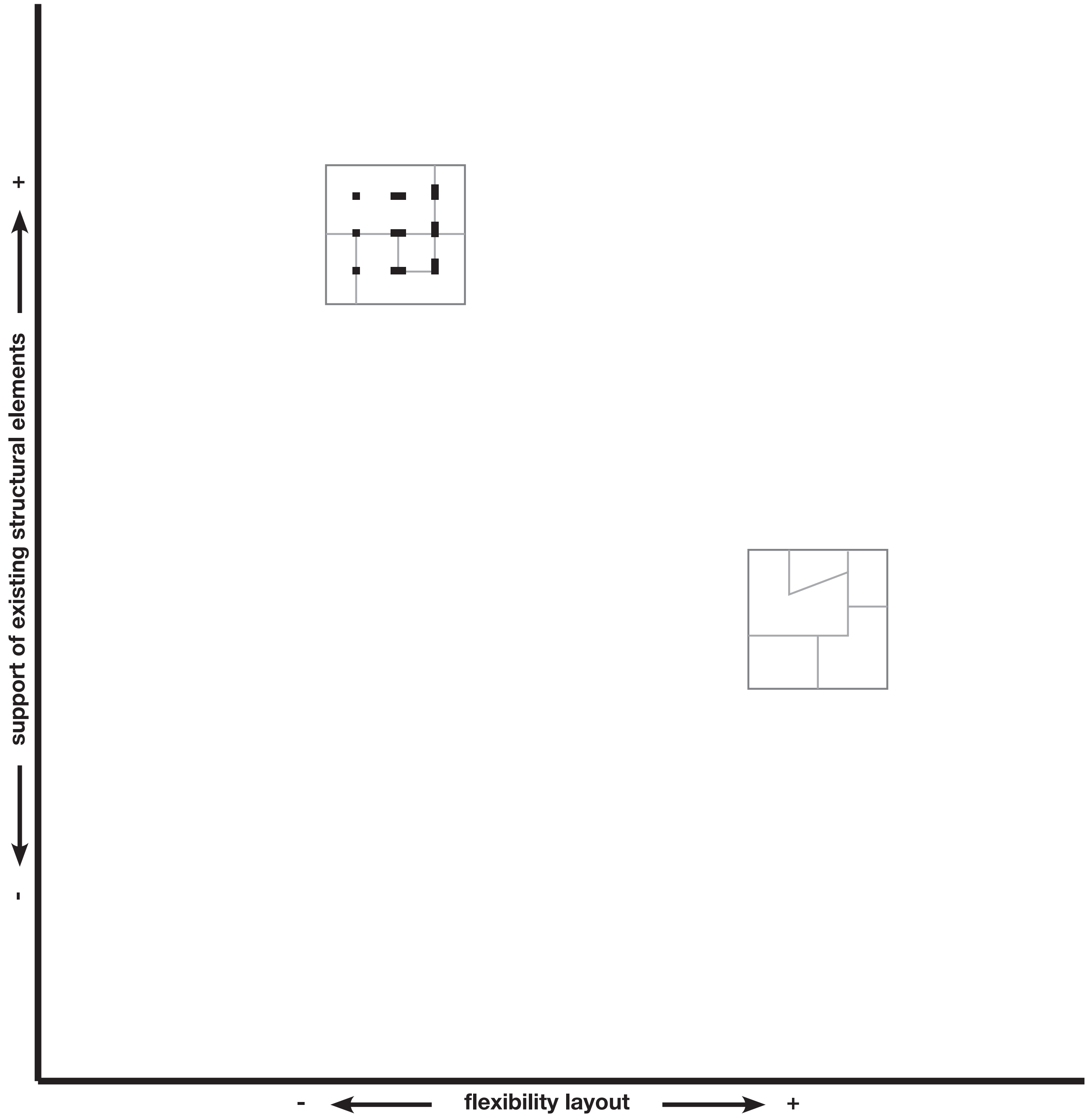


1. The location of the wet-cells is flexible
2. The space of the vertical servant elements is space efficient

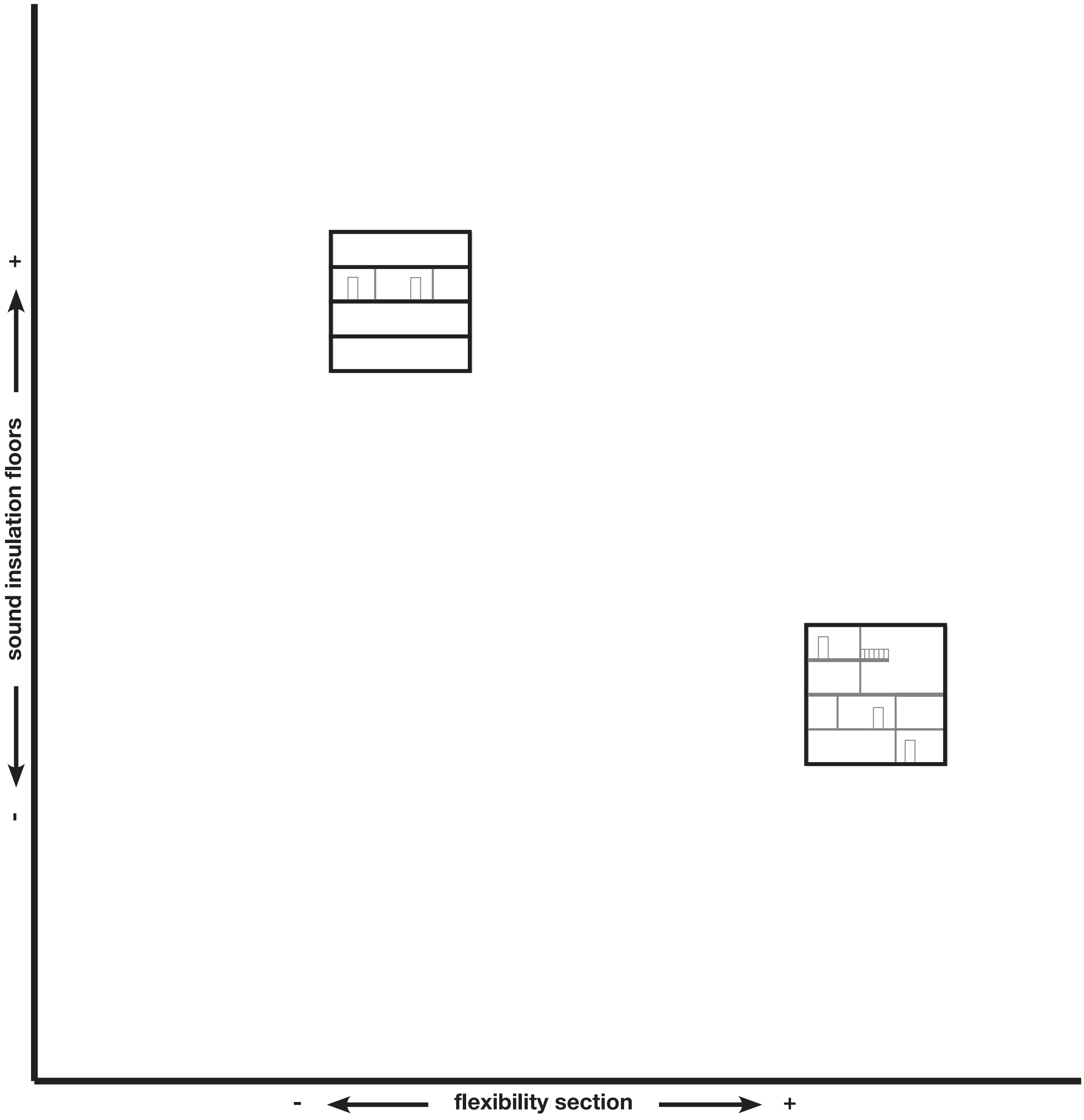


1. The location of wet cells is easy adaptable
2. The place of the horizontal servant elements is space efficient

scenery

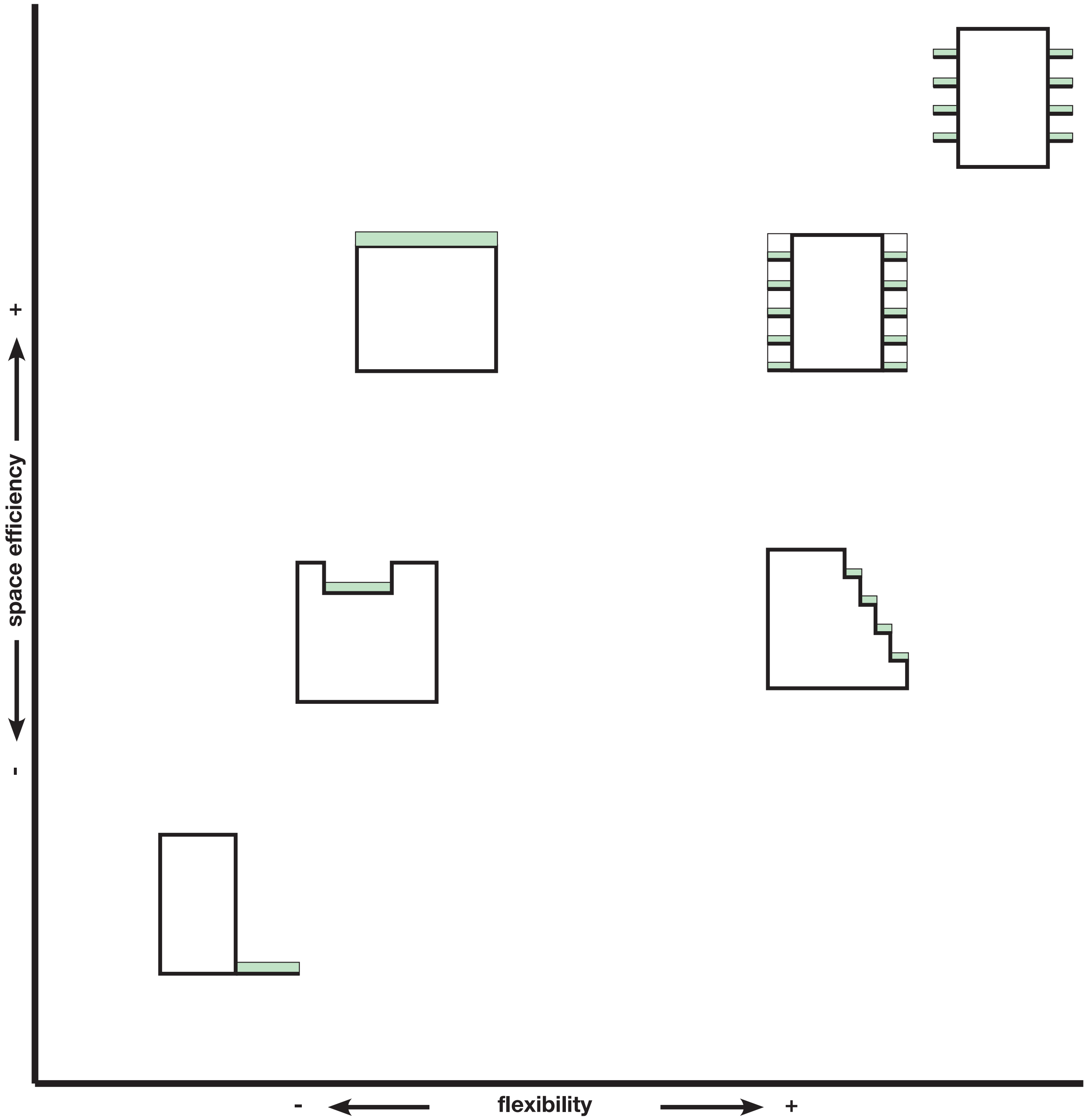


1. The floorplan of each level is flexible with minimal interference of other layers
2. A structural system gives form to the internal layout

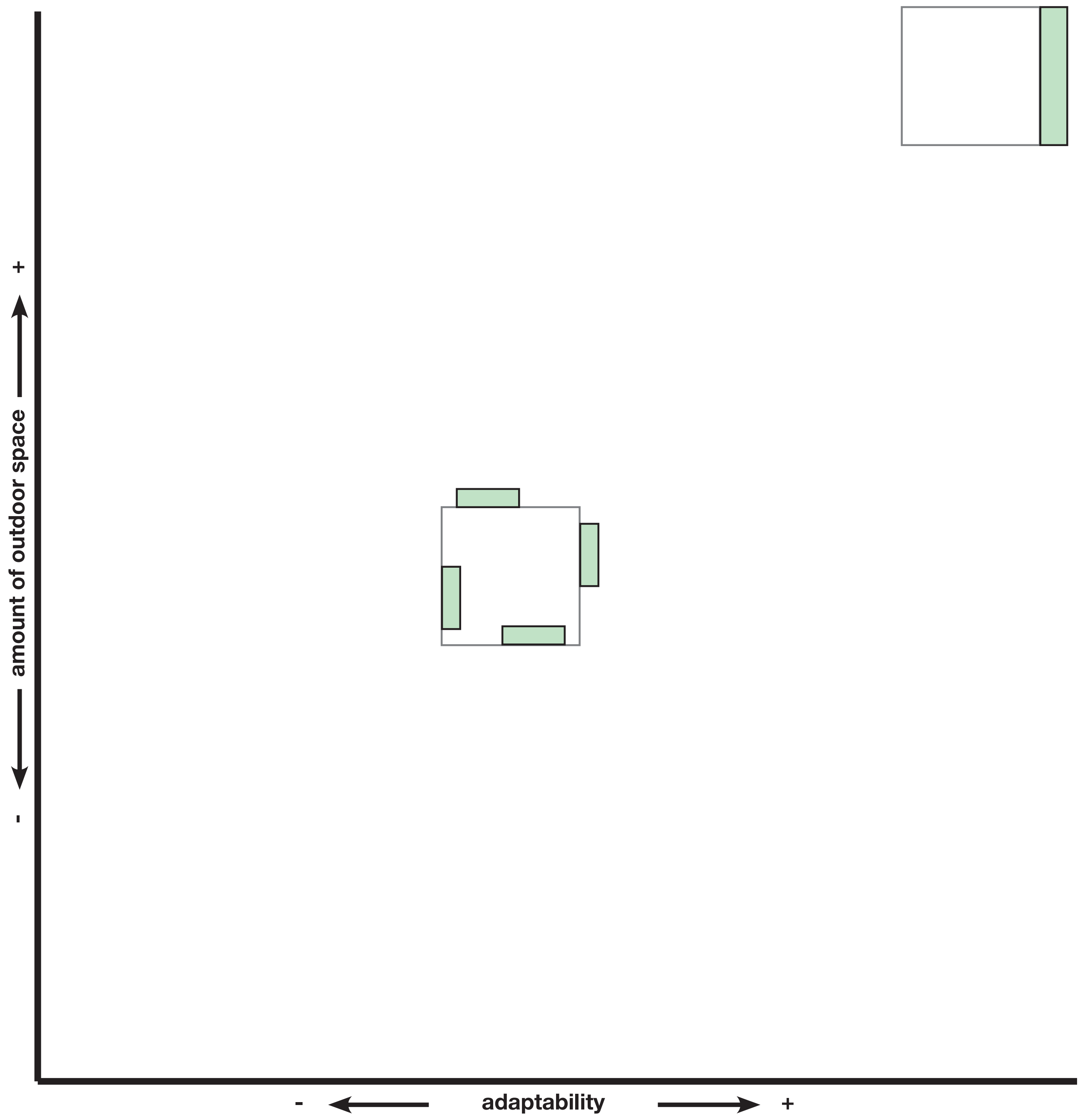


1. The layout is flexible in section due to a generous free height
2. Sound insulation between level is as much as possible integrated in the permanent structure

outdoor space

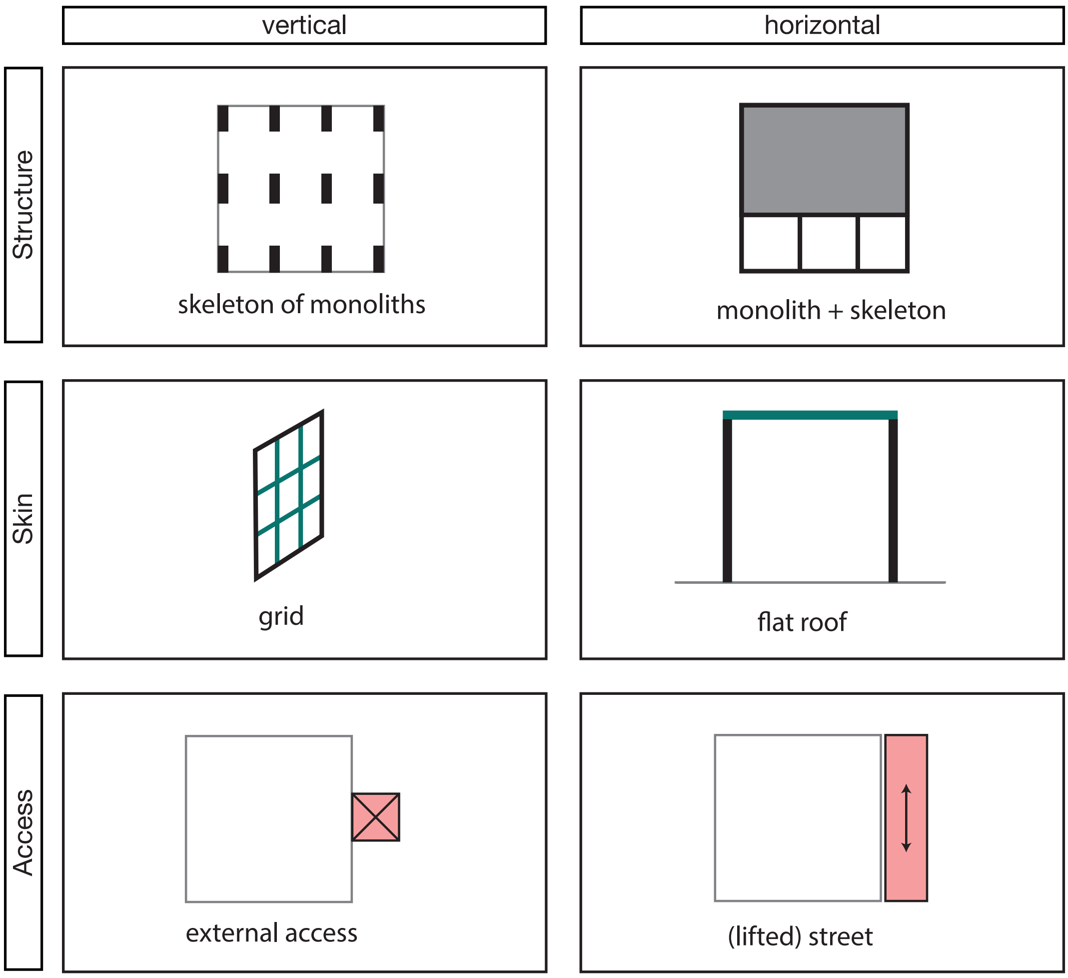


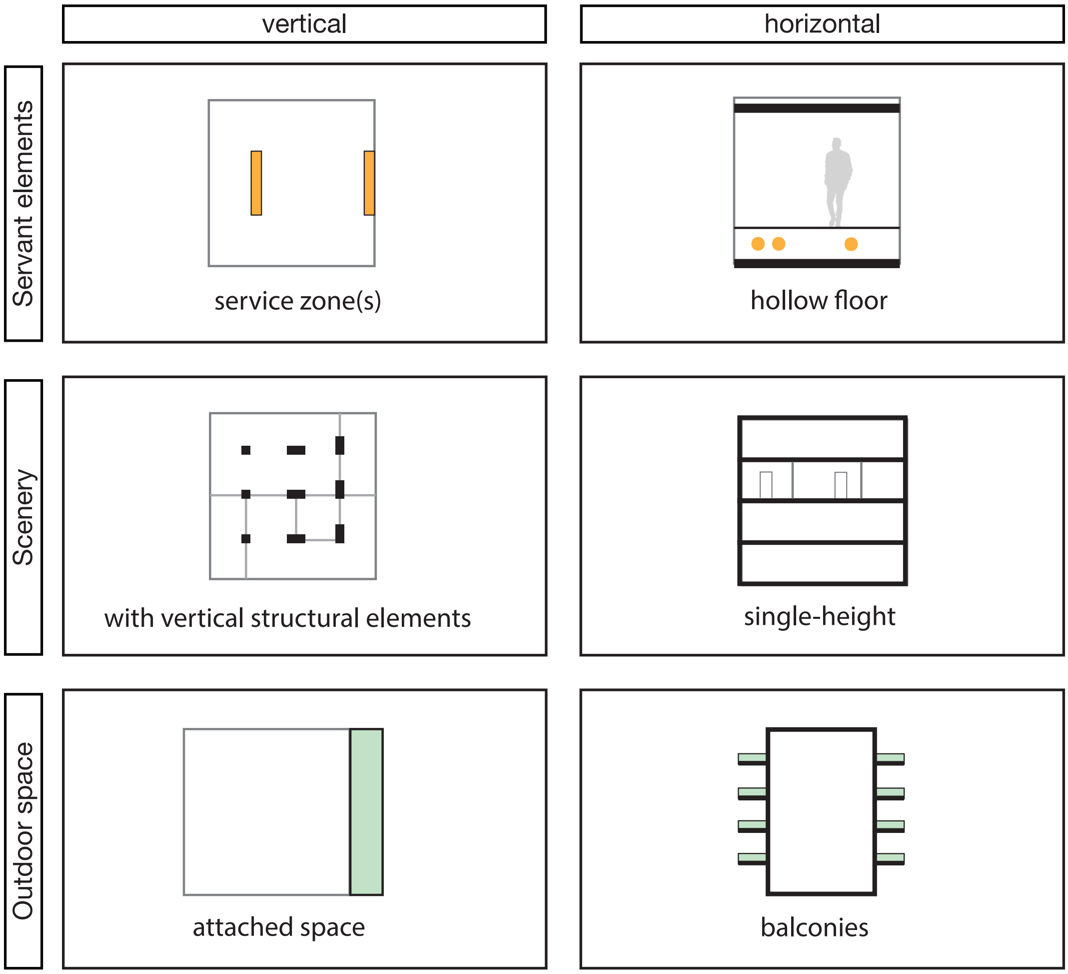
1. Outdoor spaces can be divided in smaller outdoor spaces
2. Outdoor space are space efficient



1. The outdoor space is adaptable
2. Each unit has as much outdoor space as possible

results zoning optimal layer types




vertical
horizontal
Servant elements
service zone(s)
hollow floor
Scenery
with vertical structural elements
single-height
Outdoor space
attached space
balconies