Towards Participatory Design of Dwellings

Reflections on the architectural design of modular mass-housing complexes

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Abstract

Residents often have a negligible impact on their living units spatial layout in mass housing projects. Building industry lacks tools provided to the users to create space tailored to their preferences. The purpose of this research is to address that gap by adapting issues related to product architecture and seeking the benefits of describing space through human activities performed in it. The objective is also to search for a modular solution allowing for free aggression of space by people without architectural background. The methodological approach used in this research was Research Science Design.

Keywords:

Space configuration, Collective design, Participation, Architecture, Residential, Mass customisation, Product architecture.

1 Introduction

1.1 Context

The location of a residential unit is often mentioned as the most critical factor when choosing a place to live. The decreasing variety of apartment plans of newly built blocks results in the inability to choose a flat suited to users preferences. Currently, investing entities create mass dwelling based on a clear principle: they want to make it efficient and as profitable as possible. This process results in progressing simplification of buildings structure, although modern families structures become more divers example the standard two parents, two children family become much less common. [1]

The complexity of creating space in the mass housing context is a challenge even for experienced architects. Therefore, a particularly tricky and interesting issue seems to be to involve users without any preparation in the process of creating a residential housing estate. As well as enable residents to make well-informed decisions on their own. An additional difficulty is a collective creation, which requires a kind of universal language.

The purpose of this research is to search for alternative solutions. To search for a way based on a system of modular components giving users the freedom to configure the spatial layout of an apartment independently, to seek appropriate solutions on their own.

1.1.1 Societal relevance

Choosing a flat is arguably one of the most challenging decisions in human life. It is associated with enormous costs, frequently linked to a loan taken out for years. Involvement of users in the process of creating collective housing gives the possibility to create an inclusive housing environment. Creating an environment in which the end-user is positioned in the first place. For this reason, this topic seems to have significant social relevance.

1.1.2 Scientific Relevance

Recently, projects of digital platforms such as Modrule [2] or Barcode [3] has been developed. The primary objective of those platforms is to support user participation in the process of residential housing design. They are based on the collection of information in order to generate the most appropriate layout tailored to the needs of individuals.

However, not much has been done to provide users with tools to help residents to create their spatial compositions in large scale projects. This research aims to equip the Open Building Concept with a tool to support its implementation and build a bridge between modularity and customisation in the context of the building environment and mass housing projects.

1.2 Research Objective and Research Question

1.2.1 Research Objective

The objective of the research is a formulation of a method for the structuring of modules. The modules are intended to enable users, without architectural background, to configure spatial layouts of their dwellings freely.

At least three aspects must be addressed, to formulate an appropriate method. Firstly, users must understand the logic behind the module structure. So this research aims to determine the elementary function of modules. Secondly, the construct of an interface between the modules needs to be set. The key is to limit the number of elements providing many configuration possibilities. Thirdly, it is necessary to set standards to universal dimensional systems suitable for the representation of residential architecture.

1.2.2 Research Question

How to structure the module in order to allow users to freely structure the spatial layout of dwellings in the context of mass housing?

1.2.3 Subordinate questions

1) Which elementary function should determine modularity in the context of users' understanding of space?
2) How to structure the interface between the modules to get a system consisting of a minimum number of modules with many configuration possibilities?
3) How to create a dimensional system to achieve modular system integrity?

1.3 Research Methodology

The methodological approach adopted for the development of the framework was design science research. It is a relatively new approach to research [4] which aims at defining innovative concepts and creating a new reality instead of explaining the existing reality or trying to make sense of it. [5] Design science research looks to develop valid and reliable knowledge and utilises gained knowledge to solve problems, create changes or improve existing solutions. [6] This type of research involves the construction of a method for solving a domain problem, which must be evaluated by value or utility criteria. [7] This type of approach has its roots in the field of IT systems development. Despite this, many authors, such as Voordijk [8], find it widely applicable to create concepts for solving problems in the Building Environment. [7]

1.4 Proposed Methodology

This research explores the characteristics of the modules and checks their validity in the context of the functions found in residential buildings. For the evaluation of modules with different characteristics, an evaluation based on relevant criteria must be developed. Modularity, based on a spatial perspective, has not been extensively investigated in the context of residential buildings. Therefore it is difficult to find relevant criteria in the literature.

The proposed methodology includes the utilisation of product modularity as a framework for a system capable of providing the user with the possibility to create spatial layouts of apartments independently. The analysis and explanation of the product architecture allow for a deeper understanding of structuring a system to provide it with a potential of application in the building industry.

This paper presents the concept for development of residential buildings, which uses the division into subsystems providing a framework for allocation of responsibilities between different stakeholders to enable users to participate in the process.

This research adopts the concept of activity included in the work of Mary, Simeon and John [9] and utilises it to determine the primary function of the modules. Also, the paper presents the concept of categorisation of functions for primary (activities) and secondary (movement, accessibility) used respectively to determine the purpose of the module as a mean for the interface creation. The classification of accessibility in a residential building was presented as a basis for spatial layouts creation. The gamification was utilised to create simple rules of system functionality. The system adopts the principle in which the creation of apartment layouts is to become as simple as laying the Lego.

The proposed methodology is based on a system of dimensions created on the basis of a 3-dimensional grid allowing for coordination of work during the design process. Horizontal dimensions of the grid were established by analysing the way a person moves in space and determined on the basis of the minimum space needed to move within the building. Vertical dimensions were determined from the dependencies related to diagonal movement and associated with the staircases.

Furthermore, an analysis of the existing systems of proportions and relationships between dimensions defining the individual essential building elements emphasising the way a person moves in space is used to propose an alternative system of dimensions on which the modules could be based.

1.5 Problem Statement

The design process should be inclusive in the sense of participation of users in the decision-making process. So that mass dwellings structures become more diverse and fulfil users requirements. Unfortunately, residents do not have a significant influence on the spatial layout of their living space. This research aims to create tools which, when applied, will give the user a real chance to influence the layout of the living space.

1.6 Research Scope and Delimitations

The collective creation of space is a complex issue related to many factors, such as the division of responsibility, financing, ownership, or methods of communication. This article presents only the proposed method to be part of a more comprehensive system dedicated to the participatory creation of residential buildings.

This paper focuses mainly on presenting an alternative way of creating components and the way of structuring interface among them. This research is part of more extensive research focused on the creation of a computer-aided system to include residents in the process of creating mass housing.

This research focuses on the spatial requirements of modular systems. It ignores aspects related to their technical implementation. The aim of the research is not to present a ready-made system but rather to determine the directions of further research.

Therefore, this research is a prospective study because its main task is to understand how describing space through activities and their spatial requirements can influence and help the users to modify the spatial layout of space. Furthermore, the task of this research is to investigate human activities and their influence on the modularity of space.

2 Literature Review

2.1 Open Building Concept

The concept, which gained some popularity among the architectural community, and which addresses the problems of users' participation in the process of building fabric formation is the Open building Concept created by Hebraken. The concept is based on the idea of organising the design process on the basis of environmental levels. The idea of environment levels has its history, but its formulation is entirely new, formed in The Structure of The Ordinary: Form and Control in the Built Environment. [10]

Each level has a specific relationship in which higher - support level contains and limits lower - infill level, while in return, the lower level sets the requirements for the higher level. [11] For example, an urban street pattern, perhaps centuries old, defines plots of land on which individual buildings are constructed, demolished and new ones built over some time during which the street grid remains stable. [12] The distinction between levels was bound to levels of decision making. Each level was a subject to a different decision-making body.

The formalisation of the concept has led to the development of systems that aim to adapt building elements to the required modularity to create a more compatible building environment. Attempts to coordinate positional and dimensional elements have led to the creation of modular coordination system. The modular coordination system is the process of organising the dimensions which can be applied to any type of building. [13] The grid was based on the basic module of 10 cm and the 'tartan-grid' of 10-20 cm, and its introduction made it possible to cooperate between suppliers with the division of responsibility for a given environmental level into individual sectors. [11]

The changes taking place in the building industry caused a change in thinking about modularity in architecture. Systems started to develop in terms of compatibility of connections between individual elements. An example of systems developed in 1988 was Total Roof in which a fixed frame was complemented by elements of equipment such as windows, roof bays or chimneys. The system worked in a similar way to Lego bricks. The components could be freely combined and reconfigured based on users' preferences. [11]

Open building concept provides a methodology framework based on its assumptions. There has been a development of technology addressing the subject of modularity of the building tissue. However, not much has been done to provide users with tools to help them implement the concept in large scale projects. To help residents to create their spatial compositions.

Providing residents with the possibility of filling the space without equipping them with a set of appropriate tools forces the need for cooperation between the architect and the user. Undoubtedly, it has many advantages for users, such as the possibility of consulting their ideas with an experienced person. However, it is not time efficient and results in an extension of the design process. Therefor courses significant difficulties in the implementation of participatory solutions in complex, large-scale buildings.

2.2 Product Architecture

Product architecture is relevant because its analysis may allow understanding on what basis to create elements to make their configuration understandable for the user. According to Urlich [14], the architecture of the product is the scheme by which the function of the product is mapped onto physical components. He defines product architecture as three different elements: the arrangement of functional elements, the mapping from functional elements to physical components and the specification of the interfaces between interacting physical components.

The functional elements determine the purpose of the product. Physical elements are created to perform a given function.[15] Depending on the scale of abstract analysis, we can define a particular hierarchy of levels. [16] [17] In the most general level, a functional structure can be one functional element provided by the whole product and, for a more detailed assessment, can be divided into many functional elements based on smaller-scale parts. [14] When designing product architecture, it is necessary to define a set and scales of sub-products somewhere in between these extremes to find a solution closest to the customer's expectations. [7] Modules defined by the selected criterion can be combined to perform more complex user-defined functions.

The mapping from functional elements to physical components as the name states consists in determining a set of physical elements belonging to the performance of a given function. The mapping between may be one-to-one, many-to-one, or one-to-many. [14]

The interface specification is responsible for the determination and compatibility of the individual modules. The larger the number of interface types, the less freedom to create configurations. Urlich [14] specifies several types of module architecture. The most desirable type is sectional, where each element has an interface of the same type, and there is no need to have an element that connects all the others.

2.3 Formalising apartment requirements from the user perspective

Every physical object, regardless of its size or shape, can be presented as volume. In the paper "Formalising building requirements using an Activity/Space Model" [9] created to search for a modelling standard of a product of building, the authors present a reasoning path oriented from activities to their spatial requirements. The paper presents the concept of activity decomposition, which is the division of complex activities into individual spatial envelopes. Or instead as a simplified approximation of their spatial envelopes by rectangular parallelepipeds. [9] This way of presenting elementary activities together with their relations is a method of describing a given set of activities related to the primary activity and as a result of the distribution of a given space of an object is possible, separated by physical elements or imaginary boundary, into elements assigned to a specific human activity.

2.4 Human Dimensions and dimension systems

For many centuries, representatives of many scientific and artistic fields have shown interest in the dimensions of the human body. This topic is suitable for this research because many interior dimensions are adapted to the dimensions of the human body.

Especially important for this research are the functional dimensions ("dynamic") describing human dimensions measured during the activity.

Attempts to combine ergonomics and architecture through the medium of geometry have been applied in the work of Vitruvius, Alberti and Le Corbusier. [18] It is possible that the depiction of the "Vitruvian Man" by Leonardo da Vinci and Alberti's understanding of harmonic proportions were the inspiration for Le Corbusier to create and propagate a system called "the Modulor". [19]

The basis for creating the Modulor system was to standardise and rationally organise production based on a universal dimensional system and to define the system as having an unlimited number of combinations using the ideal number. After many experiments, Le Corbusier developed a system based on six-foot-tall (1,828m) English male body with one arm upraised. This dimension is transformed on the principle of geometric constructions with golden division creating a sequence of numbers following the logic of the Fibonacci sequence.

The Le Corbusier modulator is a brave attempt to introduce dimensional unification in architecture, but it also proves that there is no limit to such an approach.[18] Einstein commented on the attempt as a will to create "scale of proportions which makes the bad difficult and the good easy". [20]

Despite successful attempts to implement the system in the Unite d' Habitation in plan, interiors and facade detail, it was not widely adopted. Opponents accuse Le Corbusier of basing the system on the imaginary number, lack of cohesion or unawareness of actual human proportions. The Modulor has also been criticised for very impractical values to smaller dimensions and not favouring ease of construction. [19] Nevertheless, his works record the practical and metaphysical problems of this approach and show how difficult it is to combine human shape with geometry and architecture. [18]

2.5 Examples from practice

There are several examples from practice relating to users' participation in the design process of residential buildings. In addition to the apparent differences associated with the aesthetical appearance, the way the system is structured defines the flexibility significantly for users to create their own space. Moreover, it determines the nature of the influence and control of the architect and other stakeholders on the final shape of the building. In other words, it defines the responsibility of individuals in the design process. Types of approaches, together with examples, are described in the following.

2.5.1 Grid + Infill

The first example of the approach is based on a modular grid assembled from structural components complemented by physical parts of the building's structure, namely horizontal and vertical partitions. The selection of filling elements is based on users' preferences. This system ensures flexibility in shaping the internal space. It also provides control over the final effect by the architect, in the case of which the given object has a controlled outline. An example of such a solution is a project called "Modular affordable housing envisioned for "abandoned" New York airspace" designed by Jenna McKnight.

Fig. 1 Visualisation, "Modular affordable housing envisioned for "abandoned" New York airspace", source: www.dezeen.com.

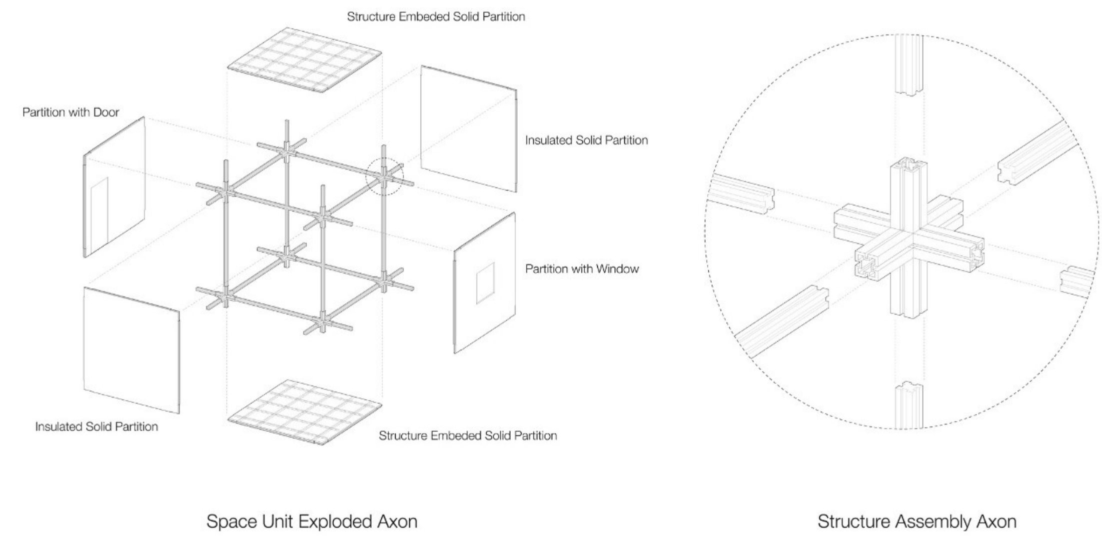

Fig. 2 Diagram of system functioning, "Modular affordable housing envisioned for "abandoned" New York airspace", source: www.dezeen.com.

2.5.2 Self – Bering units

Another example of an approach to user participation is a system in which each of the modular components is an independently functioning load-bearing unit. Thanks to multiplication, it can be the basis for larger arrangements. A project used as an example is Habitat 67 designed and built-in Montreal for Expo 67 by Moshe Safdie.

Fig. 3 Photo by Wladyslaw, Habitat 67, Safdie Architects, source: www.archdaily.com.

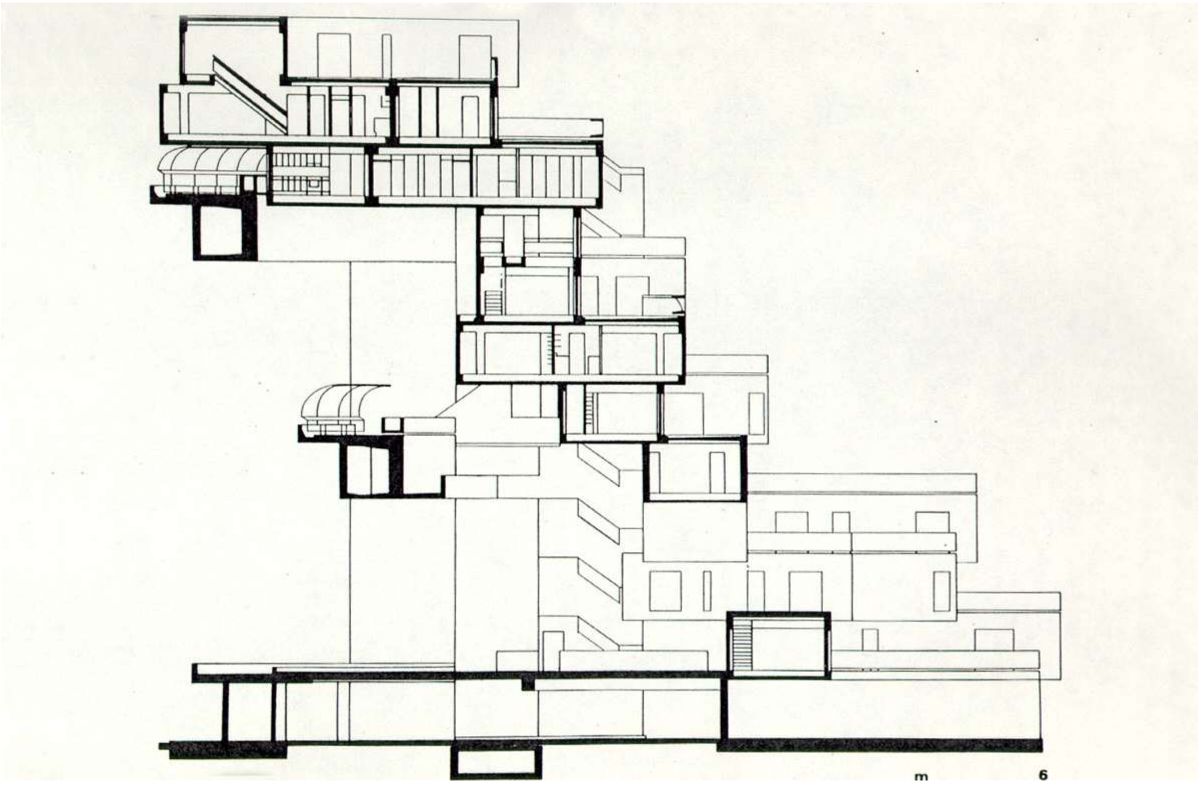

Fig. 4 Section, Habitat 67, Safdie Architects, ©Canada Architecture Collection, Mcgill University, source: www.archdaily.com.

The concept was not to involve residents in the design process but to provide affordable, modular housing with the essential benefits of suburban houses, namely gardens, fresh ar and multilevel environments. Nevertheless, it is a system that could work well with the participation of residents.

The system is built on two necessary subsystems: housing modules and a system of vertical and horizontal accessibility routes.

The disadvantage of the building is undoubtedly the lack of diversity of the proposed modules, which does not leave much room for users' interventions, and the aesthetic expression of the building, which many find chaotic.

2.5.3 Shell-like boxes + Infill

Another way to include the users' preferences in the layout of their apartment is to provide them with space that is, in fact, a freely customisable envelope. It is a relatively simple method used by architects following the Open Building Concept. There are many examples of such a solution. One of the offices using this type of solutions is Marck Koehler Architects.

Fig. 5 Diagram 1, Superlofts Houthavens, Marc Koehler Architects,

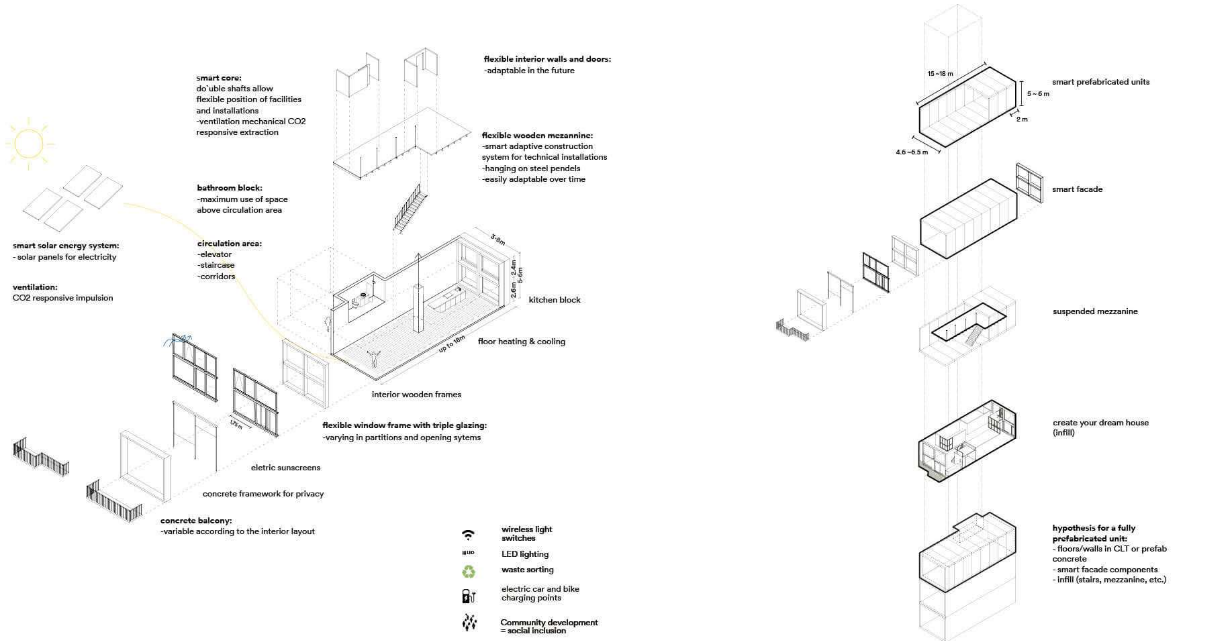

Fig. 6 Diagram, Superlofts Houthavens, Marc Koehler Architects, 2016, Amsterdam, The Netherlands, source: www.marckoehler.com

The method allows the architect to have the same impact and control over the shape and appearance of the building as conventional methods. On the other hand, it limits the possibility of users participation.

2.5.4 Add to core

The last example is the concept proposed by Liana Wu in a project called Beyond the Shell.

Fig. 7 Visualisation, Beyond the Shell, Liana Wu, The Bartlett School of Architecture, source: www.dezeen.com.

The project is based on a self - build scenario, in which modular components are used to create the possibility for users to configure living units. Components are added to the structural core, which includes stairs and lifts. An essential element of the concept is the desire to create a community through the appropriate use of the system.

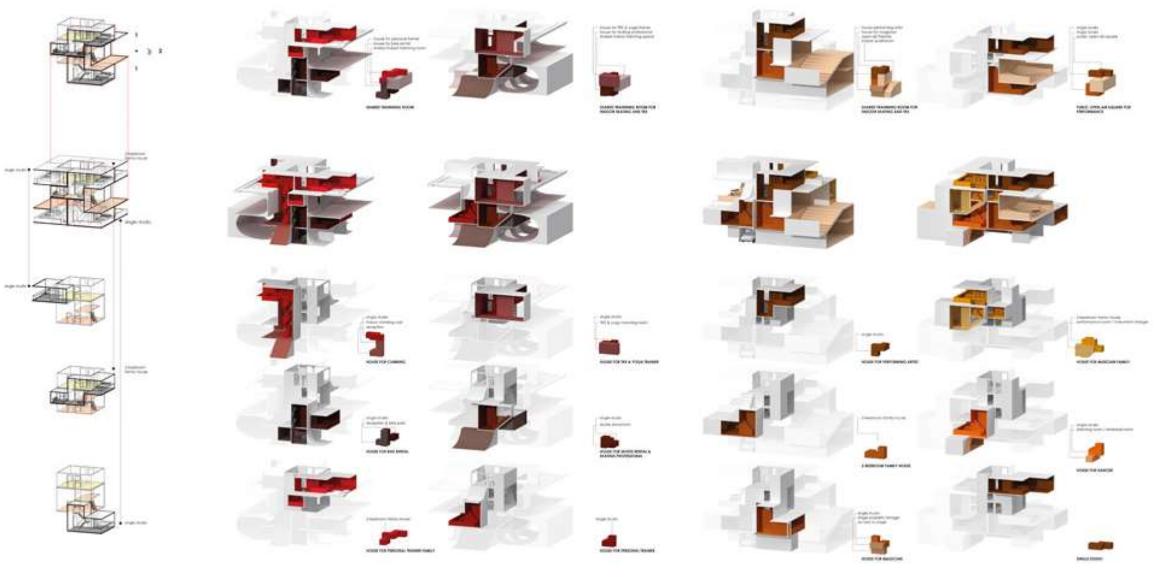

Fig. 8 Diagram, Beyond the Shell, Liana Wu, The Bartlett School of Architecture, source: www.dezeen.com.

Undoubtedly, this system gives the users incredible freedom to create configurations. However, similar to Habitat 67, it provides little control over the result for the architect. Besides, creating functional layouts from structural elements can exceed the ability of people without the appropriate background.

3 Proposed Conceptualisation

The framework presented here can be used in various types of buildings. The rest of this chapter, however, focuses on a large residential building with a layout similar to double floor gallery-access block of flats.

The proposed conceptualisation includes methods for modules structuring, interfaced formatting and the basis for creating a dimensional system. They are described as follows.

The proposed conceptualisation requires the system to be divided into four subsystems based on the functions performed by individual components and the stakeholder responsible for their design and arrangement. The purpose of the division is to provide architects with control over the final effect while at the same time creating necessary conditions for users to configure functional layouts of the apartments.

The system is divided into the following subsystems:

1. Facade

2. Components for Apartments Configuration
3. Accessibility
4. Shared Spaces Components

The concept is based on the idea that the external shape of the building is fixed over time. The external facade is a kind of envelope. Users have a specified volume which they can configure using pre-prepared components. The volume has a specified width, high and the length is freely definable as long as arrangements meet the maximum load-bearing capacity of the system.

3.1 A Dimensional System

Similarly to the modular coordination system, the proposed concept implements the construction of a 3-dimensional grid that favours the possibility of cooperation between many different stakeholders with different responsibilities. Usually, the building plan is based on a very fine grid, typically 1 x 1 cm or even 0.5 x 0.5 cm, with such a grid the size of the rooms can be varied. Although each of the rooms can be of any size, proportions and shape, in reality, the size of the rooms is limited. Such knowledge can help to limit useless room layouts.[21] Diversity based on a few centimetres difference does not significantly affect the perception of the space and the possibility of its configuration. The functional grid of objects is based on an arbitrary unit usually close to the minimum corridor width.

Subsystems need to be geometrically and spatially coordinated to enable functions to be appropriately carried out. A universal dimensional system and positional control should result in establishing a common language when making decisions at different levels.

Therefore, the system requires a division into different scales depending on the level and scope of decision making.

Scale	Level of Decision Making
Macro	Building
Meso	Apartment
Micro	Detail

Fig. 9 Table. Scale categorisation by the level of decision making.

Decisions concerning the whole building are made based on the macro-scale, which is determined by the fundamental parts of each residential building – stairs, corridors and apartments scheme. Decisions related to apartments is made on a mesoscale in which the essential elements are hidden corridors - unmanaged spaces in the apartment used to move around in it. The microscale should be based on finishing. The microscale has not been widely studied in this research.

The size of the three-dimensional grid should be determined in such a way that it can contain elementary characteristic for the scale and the dimensions of the individual system components.

The basic dimensions of the grid are based on the human activities related to diagonal movement, which essentially provides the proper functioning of the building.

Several basic dimensions such as the width of main corridors (min. 120 cm) or corridors hidden inside dwellings (min. 90 cm) should be taken into account to allow unrestricted movement around the building. When creating a functional layout, the most appropriate dimension would be 30 x 30 cm, which takes into account the previously mentioned dimensions.

However, such a grid may create layouts which cannot be directly translated into the architectural plan because the dimensions of physical building elements such as vertical partitions are not taken into account. To create a properly functioning system, it is, therefore, necessary to take into account the physical elements of building structures.

Determining the dimensions of the grid requires prior determination of the thickness of vertical and horizontal physical building elements. However, this process usually involves numerous re-iterations and re-considerations before the project is completed. These dimensions are dependent on many factors, such as the load-bearing capacity of the individual elements and the type of material used. Nevertheless, it is possible to estimate maximum values, and additional space obtained could enlarge potential rooms. The system adopted the thickness of the structural layer of the vertical partitions should be maximum 24 cm, while the structural layer of the horizontal partitions should not exceed 20 cm.

Attention should also be paid to a particular division of the horizontal accessibility within the residential building. This article distinguishes three basic types of spaces used for movement:

1. Shared communication – main corridors
2. Hidden corridors
3. Rooms with a movement function

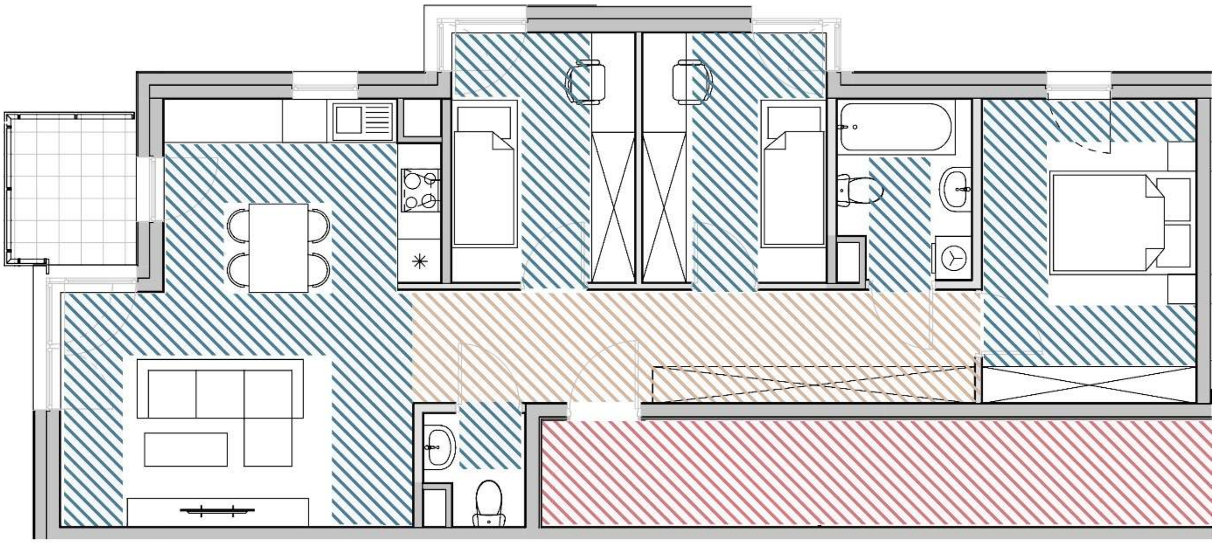

Fig. 10 Accessibility types, Red - Shared communication, Orange - Rooms with an access function, Blue - Hidden corridors. Apartment plan with superimposed colour.

Shared communication – main corridors

It is used to move within the building. Its width should not be less than 120 cm.

Rooms with an access function

Space wholly or partially separated by physical elements of the building and used for movement. The minimum acceptable width is 90 cm. In reality, however, it is commonly designed as a space with a width of 120 cm. Narrower solutions are impractical. As a rule, they have a generic shape because it is not defined in advance as the shape is usually not significant. They are usually shaped in such a way that their surface area is as small as possible.

Hidden corridors

They are used for communication within the apartment. Space included in a part of a room intended for a function other than movement.

Another example of elements that should be taken into account when creating a universal system of dimensions is stairs. Stairs are one of the fundamental modular elements used in the buildings. The height and depth of stair steps should be consistent to avoid the potential risk of tripping over inconsistencies. A regular flight of stairs provides a safety factor. Inconsistencies or variations in risers or treads could interfere with the rhythm of the individual using the stairs.

It is considered that the most appropriate angle of stairs is in the range of 30 to 35 degrees. Using the effective formula

$$2R + T = 60/65$$

developed by French architect François Blondel, which allows determining the correct dimensions of a comfortable and efficient staircase according to its use we can specify the dimensional range in which the stairs rise, and tread should be located. (R denotes rise size of the step and T denotes tread of step)

The values given have been rounded to the nearest millimetre, the vast majority of construction techniques are not more precise.

For step rise = 30°
$\tan 30° = 0{,}5774 = \frac{R}{T}$

$$for\ 2R + T = 60\ R = 28{,}0\ cm\ and\ T = 16{,}2\ cm$$

$$for\ 2R + T = 65\ R = 30{,}4\ cm\ and\ T = 17{,}5\ cm$$

For step rise = 35°
$\tan 35° = 0{,}7002 = \frac{R}{T}$

$$for\ 2R + T = 60\ R = 25{,}0\ cm\ and\ T = 17{,}5\ cm$$

$$for\ 2R + T = 65\ R = 27{,}1\ cm\ and\ T = 19{,}0\ cm$$

When considering a universal system that can be implemented anywhere, it is necessary to take into account national regulations. The legal regulations regarding the dimensions of stairs and fire protection vary from country to country. Some countries set a maximal step rise depending on the application in particular building types.

The mega-scale was determined based on the primary dimension. (multiplication of the height and width of the step, the width of the landing)

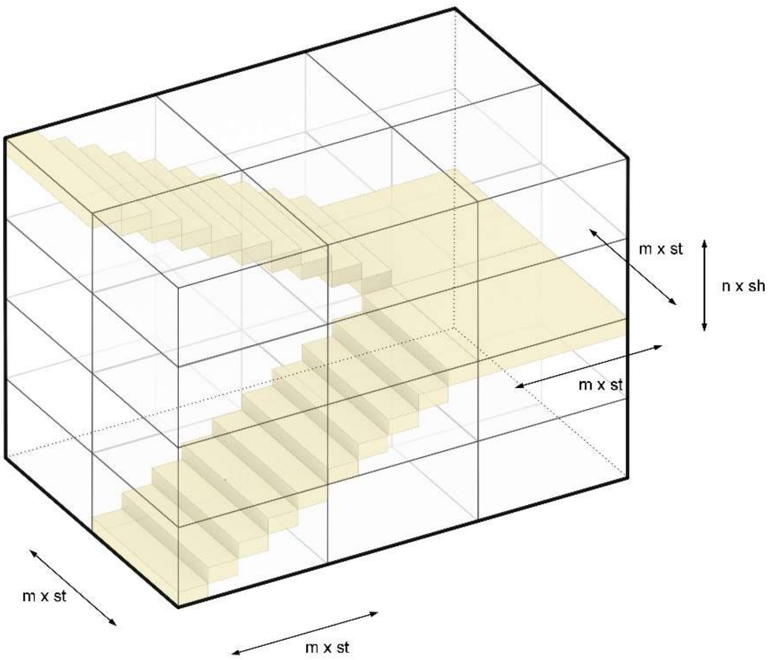

Fig. 11 The relationship between dimensions in the staircase where st - stair tread, sh - stair height, n,m - natural numbers

Dimensions of different types of corridors taking into account the thickness of vertical partitions are used to determine horizontal dimensions of the grid. The staircase dimensions are used to determine its vertical dimensions.

The primary size of the grid was determined based on the principle that at least one dimension of the room, regardless of its function, should be no less than 120 cm. It was also presumed that each of the modules should be an element working independently and that it contains half the thickness of horizontal and vertical partitions.

By adding two halves of the width of the wall to the established minimum size of the rooms, the 144 cm dimension was determined. To increase the number of possible configurations of components and to take into account the width of hidden corridors, the size of the grid was reduced four times, resulting in 36 cm. This dimension allows for free arrangement of shared communication and hidden corridors with respect to the thickness of vertical partitions. Various possible component layouts, including wall thickness depicted in Fig. 12.

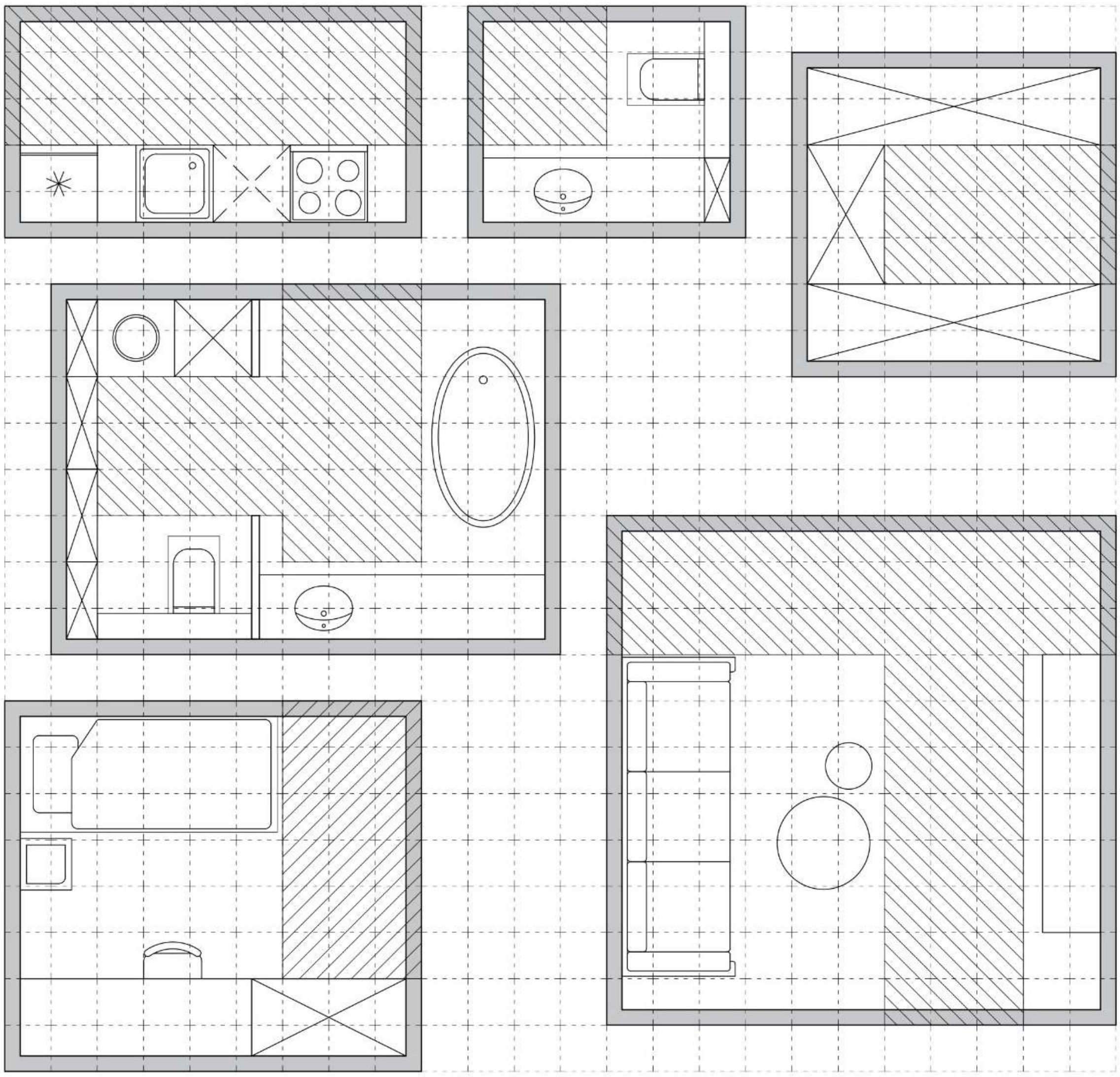

Fig. 12 Various possible component layouts, including wall thickness (12 cm) based on 36 cm horizontal grid dimension. Hidden corridors depicted with stripes pattern.

Vertical dimensions of the grid have been determined based on dependencies occurring in stair dimensions. The dimension, which is three times the primary dimension (108 cm) was adopted as a dimension that is subject to further transformations. It is the dimension closest to the width of the hidden corridor. By substituting this value to the formulas, a range from 62.5 to 75.6 cm was received. This research defines the primary vertical grid size as 67.2 cm. This value ensures the angle of stairs to be precisely 32° which is considered to be the most comfortable angle. As a result, four and a half times this dimension determines the gross height of the room (302.4 cm). The resulting stairs would have 18 steps with dimensions of 16.8 cm high and 27 cm deep.

The uniform system of dimensions, despite some limitations, provides the possibility to create a system that makes the configuration of space as easy as laying Lego.

3.2 Subsystems

The formation of a residential building is usually a long and complicated process, which is not linear. To include users preferences in the design process, it is necessary to coordinate and establish a clear structure of responsibility. Cooperation is particularly essential as many stakeholders are responsible in the design process such as the investor, local authorities, architect.

Several limits influence the number of possible solutions:

1. Resulting from the objectives set by the investor and local authorities
2. Local conditions (lot dimension and proportions, orientation climate conditions, structural constraints, building code requirements)
3. Architectural objectives (aesthetics, shape, material)

The system includes a division into individual subsystems, which enable stakeholders to share responsibilities in a structured way. The architect, in cooperation with the investor and local authorities, determines the final external shape of the building, its structure and aesthetic appearance. Additionally, the architect determines the location of shared vertical communication cores and creates a set of components needed by users to configure their spaces. All users decide on the number and type of shared spaces by voting. Horizontal communication is created generically based on user-created configurations.

The concept is based on the idea that the external shape of the object does not change over time. Users are given the outlined width of their space, while its length is freely increased, concerning the load-bearing requirements. As a result, the object does not have a fixed internal facade. The idea was taken from the way of functioning of rowhouses in the Netherlands. In which the external facade remains unchanged over the years, while most of the facades facing gardens are being continuously extended and rebuilt.

3.3 Façade

The building's facade, as a static structure, is intended to be the main structural element to which individual modular arrangements are attached. It is a form of an envelope. The facade is made of modules of a size that corresponds to a multiplication of the primary grid size. The architect adopts the design concept concerning the load-bearing requirements.

As a fixed system of the building, it should be equipped with spaces allowing for the location of vertical services shafts.

It should be made of materials capable of carrying high loads, such as reinforced concrete or steel.

3.4 Components for Apartments Configuration

3.4.1 Structuring Spatial Layout of Components

How space is used has a huge and, in most cases, a fundamental impact on how it is organised. It is impossible to imagine space without specifying the activity performed by a human being. [22] It is common to call rooms based on the activity associated with it, for example, a sleeping room or a bathroom. Therefore, it is reasonable to consider a set of tools supporting the user's space configuration by aggregating modules whose level of a functional structure is based on the activity or the set of activities performed in it.

In the building environment, there is a division into two fundamental functional elements: primary and secondary functions. Primary functions are responsible for activities carried out in space and operate with physical elements such as spatial voids. Secondary functions performed by solid masses are supporting physical elements such as walls, structural elements and roofs. From space configuration by users, it seems appropriate to base components on the primary functions they serve.

To create components that can be configured by future users, the method assumes the categorisation of primary functions into two subgroups. The main functions resulting from human activity in space and the supporting function focused on the human movement in space and the accessibility within space. The main functions, similarly to the Activity/ Space model, is described based on a spatial envelope containing a combination of all spatially related activity requirements. Human activities are considered as modifiable spatial units. Supporting functions are created as a corridor with a minimum width of 90 cm. The main functions determine how a given module is used, while the side functions are the basis for compatibility between the modules.

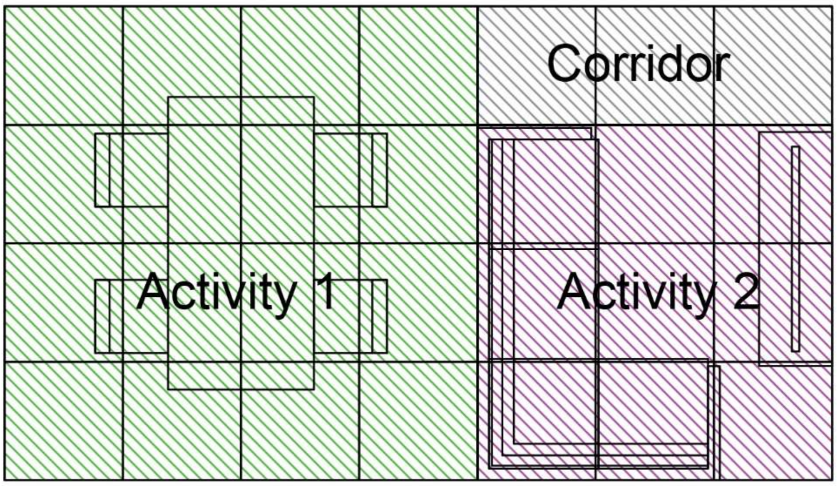

Fig. 13 Primary functions categorisation

The concept investigates the modularity of residential architecture from a spatial perspective. In which each module consists of a wide range of interconnected components. Modules are not considered at the level of specific equipment but the level of interaction between them, such as goods and supplies exchange. This paper defines modules as built as separate entities that can function independently.

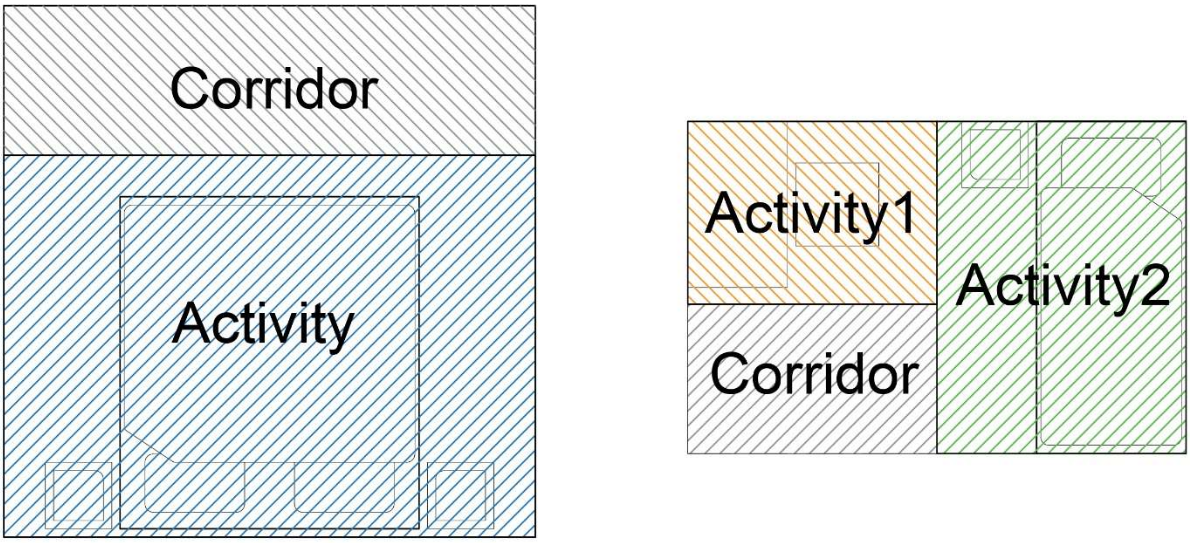

Fig. 14 Singular activity and cluster of activities modules

Each module is based on a single activity or aggregation of activities in both cases must be equipped with a support function. The reason for this is the desire to achieve an appropriate level of system complexity and scale of elements tailored to the user capabilities. It is operating on complex activities such as cooking or personal hygiene requiring an appropriate combination with related activities. This process requires precise knowledge, and what is more, it does not have a positive impact on the number of possible compositions obtained by combining the modules. The concept proposes the implementation of ready-made aggregation of activities to obtain modules equipped with pre-designed bathrooms and kitchens.

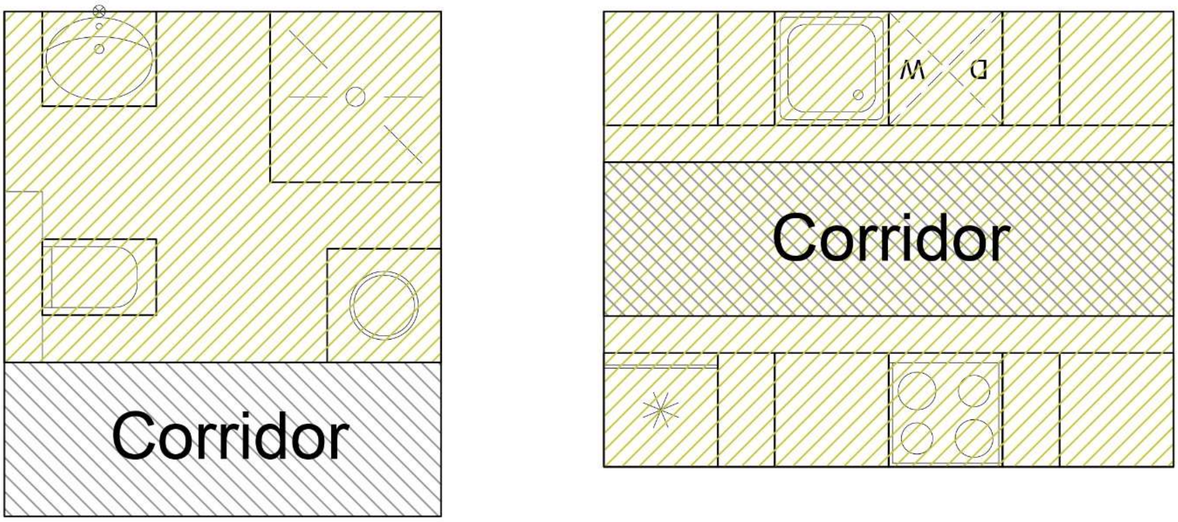

Fig. 15 Clusters of Activities, Kitchen and Bathroom

When creating spatial arrangements of the modules, it is necessary to divide them into two groups, connection modules, which connect different rooms within the apartment (usually living rooms and dining rooms) and dead – ends. Dead – ends are rooms which connect to the network of corridors only in a single location (usually bathroom and storage rooms). In practice, this division does not refer to a specific function of the room but only to the way it functions in the apartment layout.

The use of dead-ends allows for their operation in arrangements in which they can only be accessed from one direction. The connection modules should be designed in such a way that they can be connected from many directions to make the system more comfortable to use and increase the number of possible layouts. When designing specific components, it is necessary to take into account the possibilities of their use.

It is possible to create many hidden corridor layouts, such as I - shape, L - shape, H - shape, O - shape and combined layouts. The more possibilities of connection contain a component, the easier it is to create configurations in which this component is to be used. However, a too large amount of corridor area results in the creation of spatial layouts that use space inefficiently. The solution is to create a group of components based on the same activity or a cluster of multiple activities, which contains components with different corridor sizes and shapes. In a computer-aided system, the user would receive information on how effectively his space is used in the context of the space consumed by corridors. Such information would be encouraging for the user to reconfigure the system or change the components.

3.4.2 Interface Formatting

The concept includes module interface based on the ability to move between the modules through the corridors. The idea was taken from the tile-placed multiplayer game Carcassonne. In which each player receives a set of modular puzzles which are arranged to create a board. The puzzles contain four essential landscape elements (city, field, roads and rivers). To add an element, players have to match it with the other ones already arranged so that the landscape elements fit together.

The concept utilises rules of the game. Modules can be connected by matching corridors positions so that the path is continuous. The way of functioning is depicted in Figure 4.

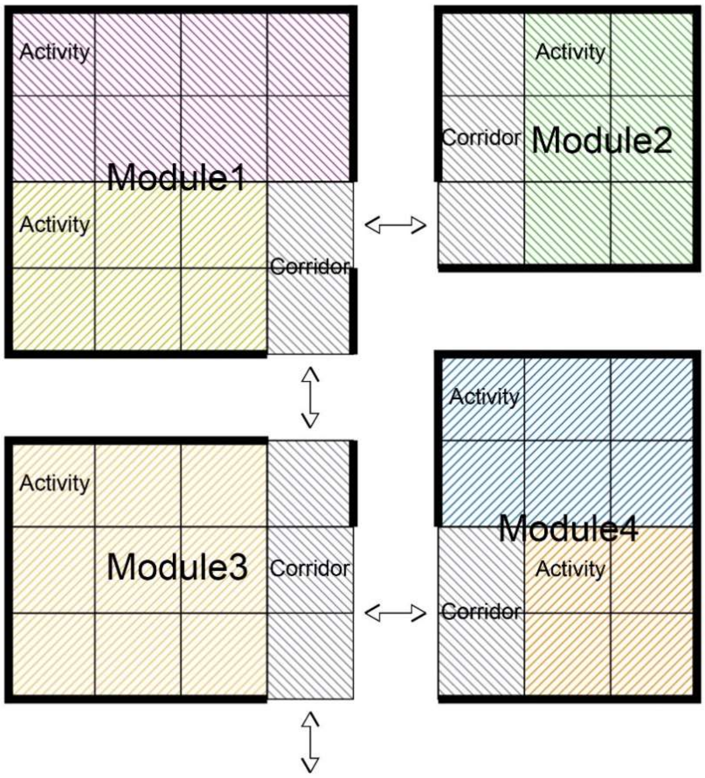

Fig. 16 Interface Structure

3.4.3 Openings

An important aspect that needs to be taken into account is to provide sufficient daylight, and thus the location of window openings. Users cannot be expected to be able to determine the appropriate window area and its location on their own. It should be taken into account that the room for permanent occupancy should have windows with an area determined according to local regulations. In other rooms (bathroom, closet) the windows are not a requirement but only an option of choice.

The location of openings often determines the possibilities of spatial arrangement or makes specific arrangements more desirable. An example is the position of a TV or monitor to the window. Thus, the system presupposes that each of the components has a specified location and the minimum area of windows. The information is indicated in the outline of the component. Components cannot be placed next to each other if the openings are adjacent to the wall of another component. In practice, a single spatial arrangement could form the basis for multiple components with different window positions.

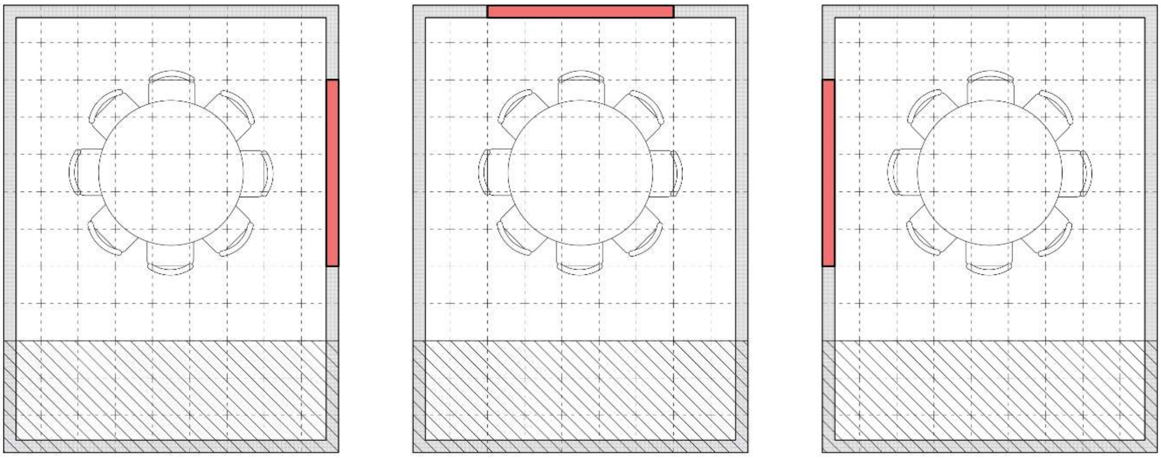

Fig. 17 Various windows positions proposition in the same activity – accessibility arrangement. Windows position is depicted in red.

Another aspect is that some functional parts requiring natural lighting (dining or cooking) can be indirectly illuminated by others adjacent to them (leisure - living room). There is, therefore, a need to create components with no windows, which would receive an additional requirement for indirect illumination. Another solution is to create systems as clusters of many activities.

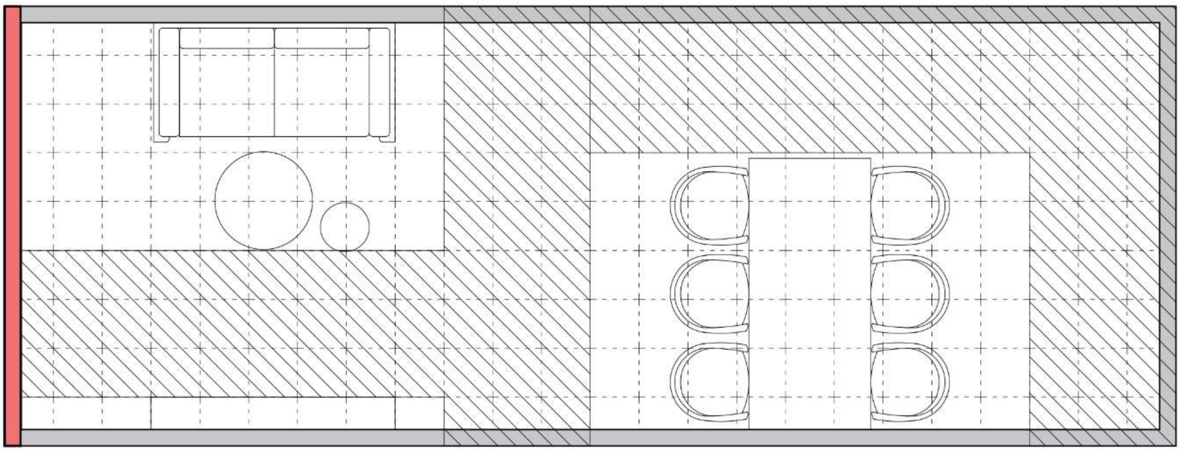

Fig. 18 Room layout with the indirect activity of natural illumination. Windows position depicted in red.

The orientation of windows and the type of activities performed in a given space is also a vital issue. In the computer-aided system, to enable users to make informed decisions, an indicator would be introduced to determine the quality of proposed layouts in the context of room orientation.

3.4.4 Components Structure

Several factors characterising each component:

1. type of activity and related equipment - space needed to perform the activity.

2. Hidden corridors shape and size.

3. Location of the window.

Those aspects define the size, shape and number of possible configurations with other components.

The concept indicates to make modules from CLT. It is a material with good structural properties and at the same time, subject to great flexibility and ease of change. The basic modules could be created as perpendiculars with the possibility of cutting out holes based on users' preferences depicted in Fig. 19.

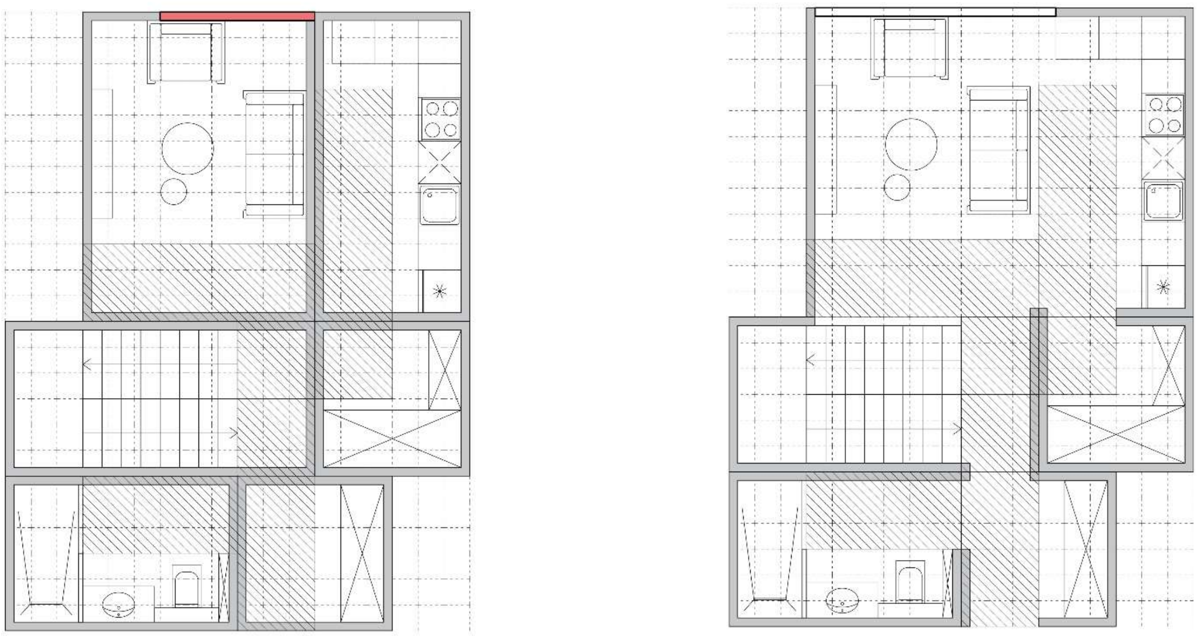

Fig. 19 Specifying the size and position of openings. On the left possible components configuration, on the right apartment ground floor after positioning openings by users.

Additionally, the floor would be raised, and the resulting void would be used to provide all the necessary services such as HVAC, plumbing etc. for the proper functioning of the building.

The components would be connected through easily disassembled connections, to ensure the possibility of reconfiguration of the systems.

The possible thickness of the insulation layer should also be considered. When using a system based on 36 cm, it is sufficient to assume the minimum width of complementary parts increased by this size.

3.5 Accessibility – shared corridors

Shared communication consists of vertical elements (stairs, elevators) and horizontal elements (corridors). The concept presupposes that the location of vertical communication paths should be determined arbitrarily by the architect. Shared staircases and elevators should be included in the communication cores.

To enable individual apartment access, the principle has been adopted that each residential module not attached to another module or the facade modules must be equipped with an attached complementary part. Complementary parts are designed in such a way that their width corresponds at least to the minimum width of shared corridors.

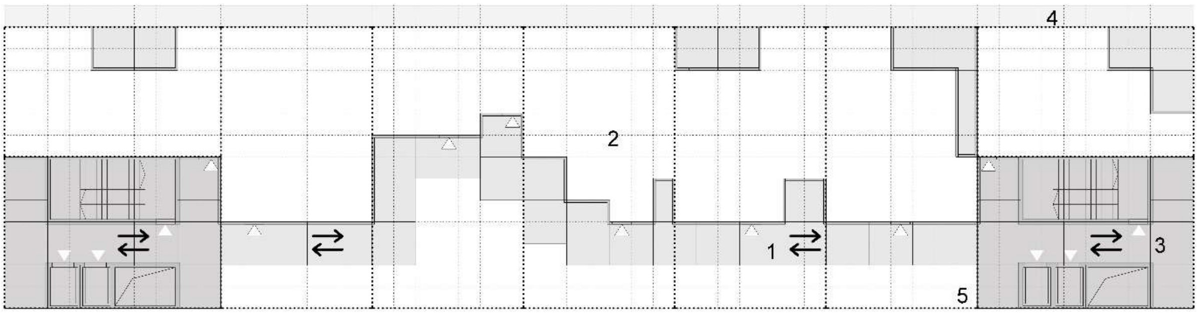

Fig. 20 Accessibility diagram. 1 – Complementary components, 2 – Apartment arrangements, 3 – Vertical accessibility cores, 4 – Façade position, 5 - Outline of maximal extension of the apartment.

Entrances to individual apartments should be located so that they can be accessible from the inner side of the building.

The distance between the vertical accessibility cores would be determined based on local regulations and the adjustment to the external shape of the building.

3.6 Shared spaces

In traditional residential buildings, shared spaces are usually located on the ground floors of buildings. Additionally, roofs are often adapted as a form of terraces with green areas. The functions are determined arbitrarily without consulting the residents.

The concept includes the implementation of a system that allows residents to participate in decisions concerning the type and size of shared spaces. The size and type of rooms intended for shared use, apart from the parking garages from the rack, is not very important due to several superior factors such as the structural or service scheme. Therefore, the system implies the creation of customised structural components made of a broader set of discrete parts whose dimensions are adjusted to the size of the adopted grid.

These components should be located on the ground floor of the building; decisions on their location should be made at the early design stage. The shared layout should be subject to expansion and reconfiguration during the lifetime of the building.

Additionally, users should have the possibility to organise their own space for social purposes.

3.7 The Procedure

The design process should be multi-stage; here are the main steps:

1. Analysis of the plot and local conditions by the architect.
2. Determining the outline of the building, the appearance of the façade modules, creating a set of components to be configured, determining the location of accessibility cores.
3. Determining the type, quantity and location of shared parts based on users' preferences. Preferences determined based on a survey.
4. Dividing the building into spaces assigned to users
5. Layout configuration by users
   5.1. User selection of components
   5.2. Layout configuration
   5.3. Feedback containing information on the correctness and quality of the created layout (price, light, room orientation, compactness)
   5.4. Reconfiguration - if necessary
6. Selection of locations and sizes of window and door while maintaining at least the minimal given dimensions.
7. Complementing the system with the necessary complementary parts forming shard corridors and adding modules to the layout preferred by users.
8. Preparation of technical drawings by the architect.

4 Results

The primary dimension of the grid adopted for presenting the results is 108 cm, which is three times the primary dimension. To ensure the proper 36 cm grid system functioning, it is required to create a much more considerable amount of components.

The proposed system requires the location of windows only facing internal or external facades.

The research presents the components as 2d drawings. Users should be able to create their arrangements using three-dimensional components.

4.1 Macro Scale

The macro-scale is oriented around decisions made at the level of the whole building, including accessibility within the apartment. Moreover decisions such as division into apartments, determining the location of staircases or corridors. The most suitable horizontal dimension of the grid would be 108 cm. However, it should be noted that these dimensions do not take into account the minimum dimensions of the shared corridor. Given dimensions include physical elements - solid masses.

Each of the modules in the horizontal projection would have a surface area of 1.17 m2, which seems to be a size accurate enough to accommodate the different sizes of apartments in the building structure.

4.2 Meso Scale

The mesoscale, characterised by greater precision of space representation, has been oriented towards the decisions related to the shaping of individual apartments. For the design of apartment components, the most precise dimension giving great possibilities is 36 cm. To form the system, however, the 108 cm dimension was used. It is associated with the need to create many components with the same layout and different sizes. The proposed system, however, does not focus on arrangements that use space very effectively. It would be necessary to adopt a smaller grid size to create smaller arrangements

4.3 Microscale

The micro room, characterised by the highest precision of space representation, has been focused on the decisions related to shaping the finish. It should be based on fine grid size, like 1 x 1 cm. Its dimensions were defined as the primary dimension.

4.4 Building Structure

One of the arrangements associated with the application of the proposed system of dimensions would relate to the structure of dwellings consisting of two floors, similar to the arrangement used by Le Corbusier in the Unite d' Habitation. Multiple modules of the basic scale give the possibility to construct flats in which the height would be

604.8 cm, while the height of individual floors would be 302.4 cm.

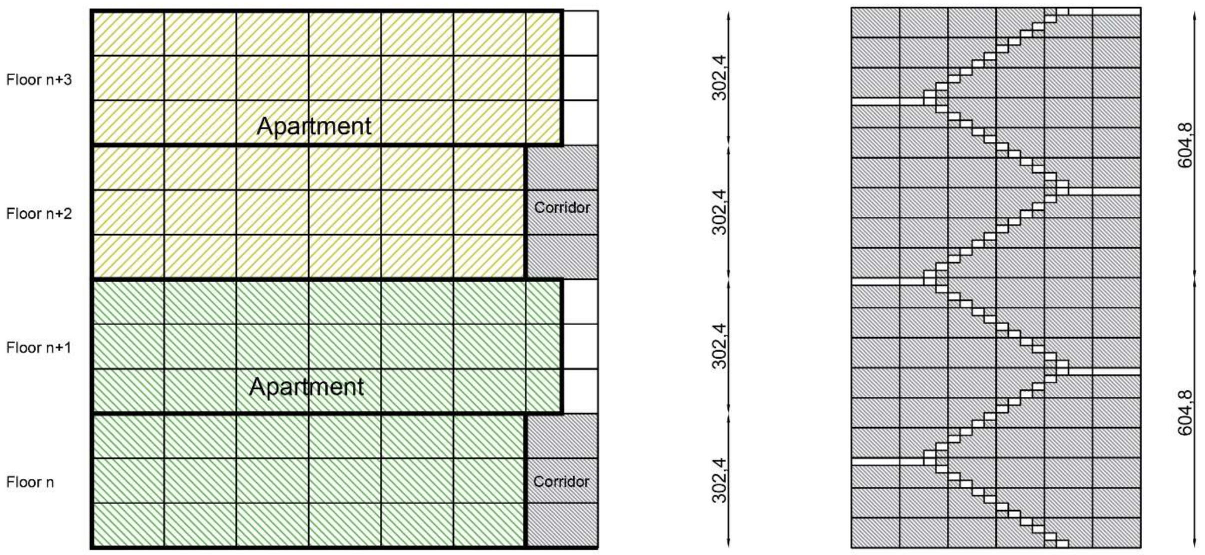

Fig. 21 Proposed building structure section diagram and staircase section diagram.

Building structure solutions with a single-storey housing unit would require the use of alternative types of staircases or the use of two with different resting heights.

4.5 Modular Components

The system would consist of an unlimited number of components. It could be enlarged in case the user wants to use a custom layout. A considerable number of components is associated with an apparent difficulty in the configuration of layouts by users. However, in a computer-aided system, it would be possible to create a set of filters to assist users in their choice and to give proposals depending on their layout. Here are examples of possible components. Components are based on a 108 x 108 cm grid. It is possible to create many versions by changing the location of the windows.

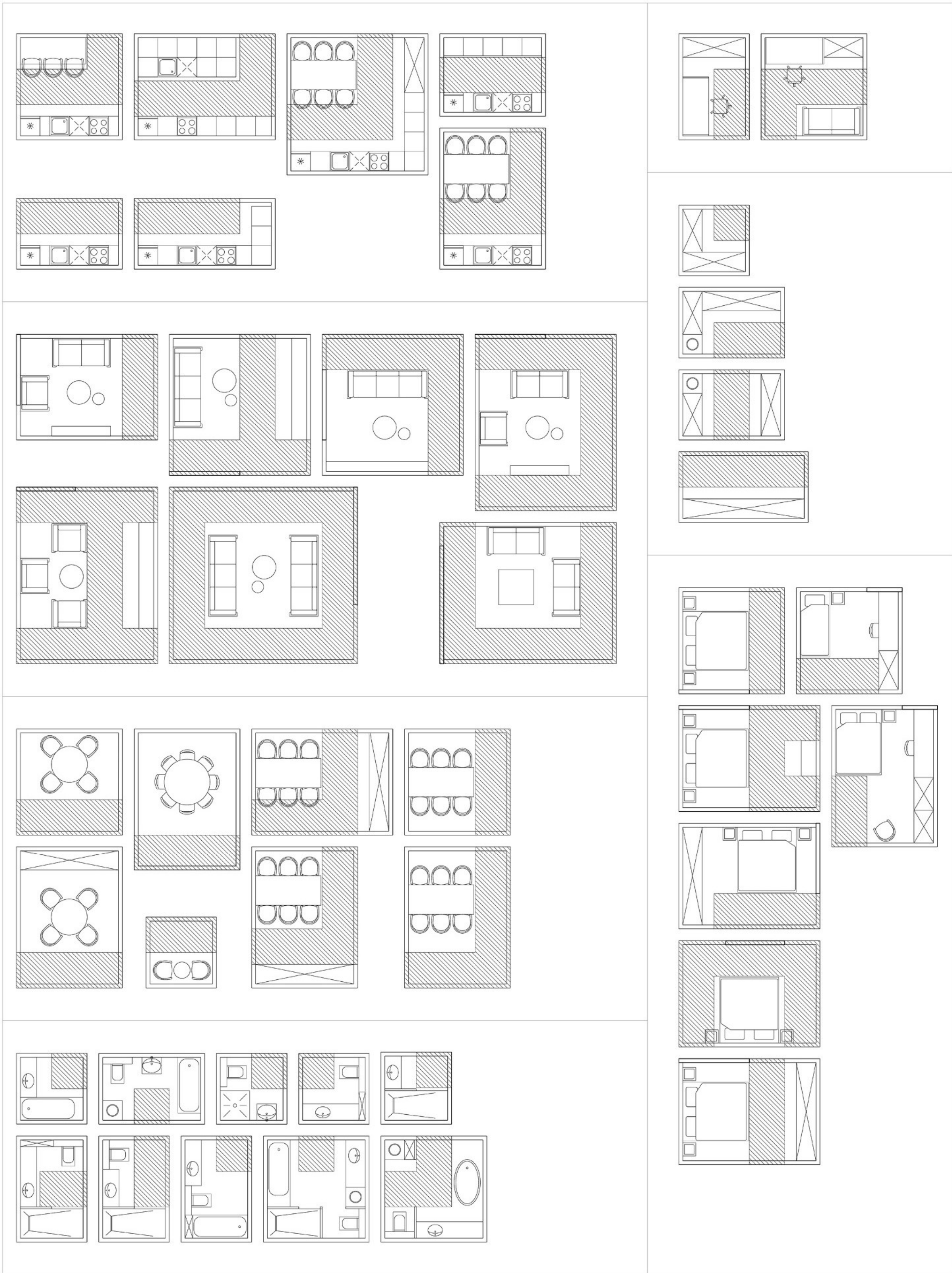

Fig. 22 Possible components configurations, horizontal grid size 108 x 108 cm.

4.6 Apartments Configurations

It has been assumed that each apartment is two-level and its width is maximum 756 cm gross. Below are several examples of possible combinations using the previously presented components.

Fig. 23 Possible apartment configuration 1. Modules configurated by the user on top. Apartment after placing openings below. Grid horizontal size 108 x 108 cm.

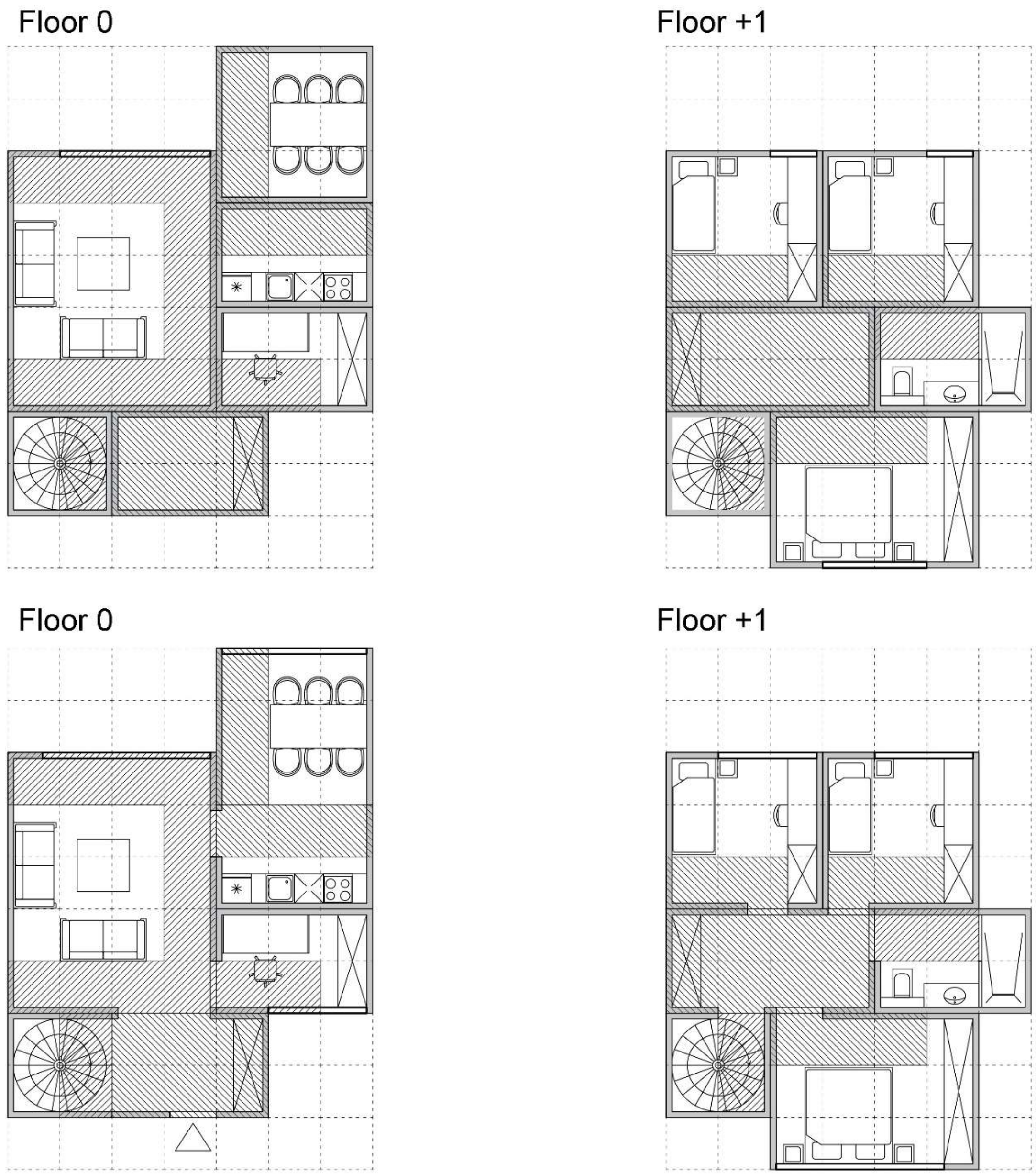

Fig. 24 Possible apartment configuration 2. Modules configurated by the user on top. Apartment after placing openings below. Grid horizontal size 108 x 108 cm.

The presented arrangements demonstrate that when selecting components, the final layout will often not be contained in a rectangular shape, creating opportunities for adaptation, for example, as spaces filled with greenery.

The system implies the creation of rooms with the accessibility function designed on a rectangular plan with various dimensions adjusted to the adopted grid size. Complications may be caused when trying to create arrangements that use space very effectively.

4.7 Possible housing plan fragment

Fig. 25 Possible fragment of the building plan. On the top apartment ground floor, on the bottom first apartment floor. 1- Façade position, 2 – Complementary parts, 3 – Vertical accessibility core, 4 – Outline of maximal extension of the apartment, 5 – Configurated apartment layouts.

The presented plan demonstrates the challenges of shaping two-level apartments. Even though it is possible to create a functional layout, it might be impossible to translate it into an architectural plan—doubts related to structural properties and stability. The principles, thanks to which building construction would be possible, should be further investigated.

5 Conclusions and Recommendations

The objective of the research is a formulation of a method for the structuring of modules, which usage is intended to enable users, without architectural background, to configure spatial layouts of their dwellings freely. The presented approach to the development of this system is an early design phase.

The paper specifies a residential building system modularity construct by defining modules structure as formed from activity requirements, relating interface of modules to the way human movement and by proposing a methodology to operationalise a dimensional system.

Adapting modularity can contribute to the development of end-user cooperation. The main theoretical contribution of this paper is the investigation of adaptation of human activities as a factor for creating primary functions defining the modules.

Regardless of this study adaptation of the grid describing the construction environment could provide a basis for further integration of computer techniques in the context of architectural design

One of the aspects related to modularity is the possibility to reconfigure the space. This aspect should be subject to further investigation.

The proposed methodology framework was used to create a prototype of a dimensional system for the representation of large scale objects. The concept is based on the assumption that modules are built as separate entities that can function independently.

Regarding future studies, at least three topics can be explored. First, this research has focused on a proximate representation of space-based mainly on pure spatial requirements of performed activities. Therefore there is still a need to explore how to include physical elements in the creation of modules. Secondly, future studies should also explore the details of interconnections and how they affect performance. Lastly, future studies should investigate the calibration of performance at both the component and the system level.

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