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ORIGINAL PAPER

Structural typologies and the architectural space—studies of the relationship between structure and space by application of structural types to multistory buildings

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Abstract
Today, architectural deliberations on structural form and structural systems unfortunately play a minor role in developing the architectural design of most buildings. This is particularly true for multistory buildings of the most common type; those for housing and for commercial purposes. Consequently, spatial, and programmatic qualities that might have emerged from an architectural study of the load-bearing structure, as well as visual and tactile experiences linked to these very fundamental tectonic elements, are in danger of being lost. Besides, a resilient and versatile load-bearing structure of a high quality may increase the building's prospects for survival over time and is hence a strong environmental argument. To counteract this present-day limitation of the structure's architectural significance, and to investigate what can be achieved by an increased architectural awareness of the spatial potential of structural form, these problems are studied in an academic context. The Oslo School of Architecture and Design (AHO) addresses in its curriculum what is here identified as a weakness in current architectural practices and offers courses on these very topics.

Keywords Architecture · Multistory buildings · Structures · Durability · Sustainability

Problem

Today, architectural deliberations on structural form and structural systems unfortunately play a minor role in developing the architectural design of most buildings. This is particularly true for multistory buildings of the most common type; those for housing and for commercial purposes. Consequently, spatial, and programmatic qualities that might have emerged from an architectural study of the loadbearing structure, as well as visual and tactile experiences linked to these very fundamental tectonic elements, are in danger of being lost. Besides, a resilient and versatile loadbearing structure of a high quality may increase the building's prospects for survival over time and is hence a strong environmental argument. To counteract this present-day limitation of the structure's architectural significance, and to investigate what can be achieved by an increased architectural awareness of the spatial potential of structural form, these problems are studied in an academic context. The Oslo School of Architecture and Design (AHO) addresses in its curriculum what is here identified as a weakness in current architectural practices and offers courses on these very topics.[1] On a general basis the teaching of basic structural knowledge at AHO is closely linked to its application in architectural design. Structures teaching in architecture schools should not be an island onto itself within an architectural education program but should be a well-integrated activity with explicit architectural ambitions. After all, the core interest that the discipline of architecture has for

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[1] Alan Colquhoun already in 1962 writes about this problem: "It is true that architects for the majority of buildings put up today make use of the simple principle of a concrete of steel frame sheathed in some form of curtain wall and in doing so appear to be putting into practice the theories of Le Corbusier in the 1920s. Yet the architectural qualities of most of these buildings are so meager that one is forced to ask whether, in the mere application of an apparently logical system, the essential features of good architecture are not being overlooked". Colquhoun [1] (1986), p. 26.

structural knowledge lies in its relevance for making varied and interesting spaces of high quality and real substance.

The thoughts we present here partly involve pedagogic strategies for structures teaching, but primarily they are concerned with architectural strategies: we let certain didactic ideas act as instruments whereby architectural design is investigated and tentatively developed. There is a slight, but important difference between the strategies that will be discussed here and the more open question of how best to teach structures in an architectural context. The latter commonly addresses pedagogic strategies to convey structural knowledge to architectural students. There are several methods in use for this purpose, and traditional blackboard lecturing is still one of them. In a paper by Emami and von Buelow [2] other important methods are summed up[2]: hands-on activities that commonly involve the use of experimental, physical models; computer-based methods that employ software to provide structural performance feedback to the user; web-based educational platforms that use online mediums to share educational materials and innovative teaching tool programs; and finally, integrating structures teaching with design studio. A common situation, however, will be that educators use a mix of the methods listed here. While our efforts can be described by the last category, the difference between the course that we do and the ever present structures courses in schools of architecture is that our aim here is not primarily that of teaching structures. Our students already have basic, structural performance learning. Our concern is to teach architecture. We teach architecture through, among other issues, structures. Our interest is the space/structure relationship, and not primarily the relationship between form, force and structural behaviour. There are obviously other architecture studios at various schools that focus on the application of structures as a strategy for architectural design.[3] On the whole, though, systematic investigations and theoretical reflections on the outcome of such studies are hard to come by. We shall try to contribute to this discourse, and we start by returning to the fundamental question of how structures may act as design generators for multistory buildings.

Background: Some historical references

If one point in our modern building history should be recognized as a starting point for the challenges relating to form, space, structure, and visual expression of multistory buildings, it must be the period starting in Chicago in the late 1870s and continued into the 1890s, which has later been known in architecture as the Chicago School. This phase is characterized by the introduction of the metal frame as a load-bearing device, with cast iron columns and wrought iron or cast-iron beams – until steel was available in sufficient quantities and was cheap enough to be of use. Buildings of 10 to 20 stories were erected, and wind bracing was provided by the surrounding masonry shell, the facade, still in a neo-classical style that refer to earlier classical epochs. The first building that went up with a bracing strategy incorporated in the metal frame itself was allegedly the 17-story high Old Colony Building from 1893–94 by architects Holabird and Roche (see Fig. 1). After this, the masonry facade became truly non-loadbearing, and the curtain wall was born.

Typical of the buildings in Chicago of this era was that the metal structure system was seen as an impressive novelty that enabled fast erection of taller and taller commercial buildings, in which only a minimum of space was occupied by the structural elements themselves. This guaranteed that valuable floor area was not lost for renting. This was a truly pragmatic view on structural decision-making, where efficient and cost-effective solutions were preferred. Building in iron-based materials also meant that structural elements had to be covered by brick or concrete as protection against fire.

A highlight of this period is the 15-story Reliance Building from 1894–1895 by Burnham and Root, and architect Charles B. Atwood, with E. C. Shankland as lead structural engineer (see Fig. 2). This was erected in "no time" and displays large glass windows as a primary material in the facade. Rigid connections between columns and beams provide bracing of the metal structure. If we study floor plans, we see four rows of columns along the length of the building, but the columns do not align in the other direction (see Fig. 3). There is no column grid. Column positions seem to be decided by where they might fit in with the location of partition walls, to interfere with building functionality as little as possible. This is a well-known strategy that is found in many of the buildings of the Chicago School. There is a certain correspondence, though, between the columns along the periphery and the way the facade is designed, where the size of window openings informs us about the ordering of the column structure behind.

Important as this era has been for later multistory buildings, there was, however, no real interest in having the structure contributing to neither the spatial experience nor to significant architectonic expression. The load-bearing structure is for the most part treated as a technical necessity crucial to the ambition of constructing tall buildings. Later American efforts in the architecture of multistory buildings during the twentieth century mostly show examples of the same attitude: even Mies van der Rohe habitually treats structures as a way of expressing and controlling his multistory building facades. The so-called "international modernism" disregarded even this point, and settled for prismatic, glass clad boxes, except

[2] See Niloufar Emami and Peter von Buelow; "Teaching structures to architecture students through hands-on activities". Canadian International Conference on Advances in Education, Teaching & Technology, July 2016.

[3] Notably, professor Christian Kerez' studio at ETH, Zurich, to mention one of the more high profiled.

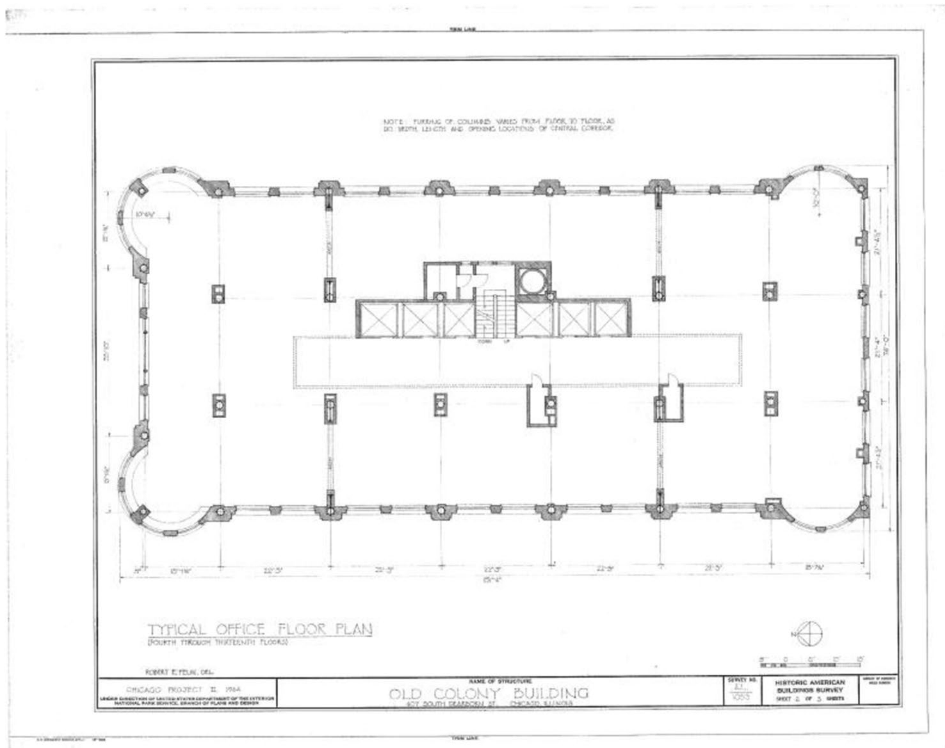

Fig. 1 Plan of the Old Colony Building, Chicago, 1894. Note the two vertical and symmetrical lines that indicate portal frames for bracing. The cast iron columns are encased in brick for fire protection. Photo; Wikimedia Commons

for some worthy examples of tall buildings where the structure system is proudly displayed on the exterior.

Two noteworthy American exceptions (among several others) to this way of thinking about structures in multistory buildings in the twentieth century are Frank Lloyd Wright and Louis I. Kahn. Wright's 14-story Johnson Wax Research Tower from 1944–1950 is a prominent example of an architecturally integrated structure both enabling, organizing, and dominating the interior spaces. His so-called "taproot" structural system is also the architectural key to his 19-story Price Tower of 1956. Likewise, Louis I. Kahn and engineer August Kommendant designed the 8-story Richards Medical Research Laboratories, finished in 1965, with a pronounced, structural idea guiding the whole complex. In his 30-story City Tower project of the 1950s Kahn anticipates later tall buildings with particularly expressive, structural exteriors.

In Europe, reinforced concrete seems to have been the material of choice for buildings of a certain height at the beginning of the twentieth century. When new building technologies and new materials gradually replaced traditional masonry structures, several buildings applying "le système Hennebique" after the French inventor of modern concrete construction, came to light. From the perspective of fire resistance this material obviously needed no separate fire protection and could be displayed for what it is. Of particular interest is the work of engineer Robert Maillart who just before the 1st World War pioneered a slab/column technology that made superfluous the need for underlying beams in slabs. This proved to be important for the architectural development of the "free plan" that sought to make spatial organization independent of the structure system.

Architect Auguste Perret's works are important in this context. He remained true to his preferred material of RC during his whole career, and he made the column his most important structural element and a necessary attribute of his interior spaces. His apartment building in Rue Raynouard in Paris from 1929–1932, also housing his own flat and studio, is a particularly good example of an interior structure acquiring a spatial presence: concrete beams and columns are displayed in the raw, flanked by panels of oak, and subtly framing in and suggesting spatial limitations while giving the space a distinct character borne of the use of noble materials and a clear statement of the act of construction (see Fig. 4). It is also classical and modern at the same time, a particular signature of Perret. Regardless of style or age, this continues to be a great example of a successful integration of structure and space in an apartment building. Later, when during the 1940s and early 1950s he rebuilt the French city of Le Havre, he was able to continue his work on establishing and evolving architectural projects by way of structural strategies, both in housing and in monumental buildings (see Fig. 5).

To suggest additional examples of interesting relationships between structure and space in, especially, apartment buildings of the twentieth century, one could do well to look at the British architect Denys Lasdun, the Italian Angelo Mangiarotti, and the Spanish architect José Antonio Coderch. Among office buildings work by the American architect Eero Saarinen and

Fig. 2 The highlight of the Chicago School, the Reliance Building from 1895 by Burnham and Root, and architect Charles B. Atwood, with E. C. Shankland as lead structural engineer. Photo; Wikimedia Commons/Mx. Granger

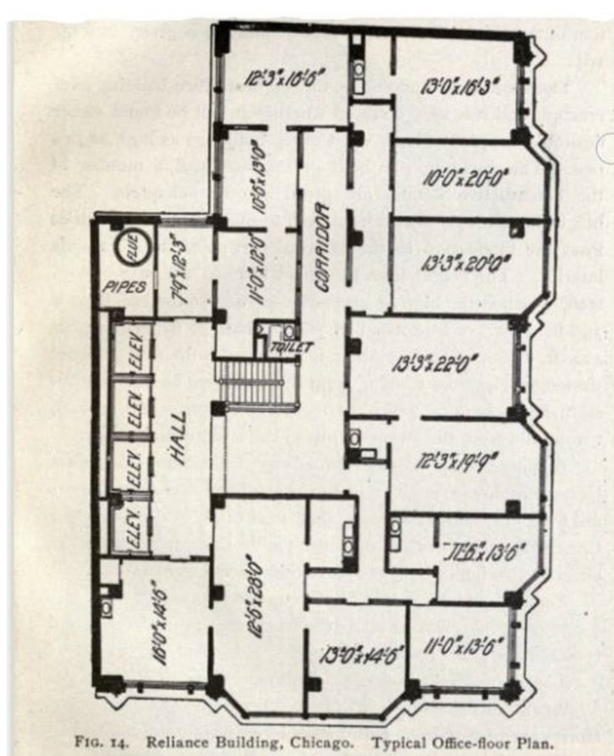

Fig. 3 Typical floor plan showing columns. Photo; Wikimedia Commons

much of SOM's work of the same period stand out, among others. However, when the tradition of the originally British, so-called High-tech architecture set in during the 1970s, structures became for the most part exposed to the exterior, to the climate, with the implicated problems that accompany this strategy. These problems are further amplified by the fact that many of the buildings in this category are in steel. Great buildings were erected by several of the world's most gifted architects, but the leaning towards a design of flamboyant and exposed structure systems may seem to exclude that approach from serving as a relevant way forward today.

There are role models, though, among contemporary architects who do interesting work in this area of structure and space, and who can inspire the design of multistory buildings.[4] These would include architects like Christian Kerez of Zurich, who relatively recently did the office building Confluence Îlot A3 in Lyon, a work of high quality that picks up on some of the best traditions in reinforced concrete structures, resulting in most pleasant interior spaces and an attractive exterior. Also, the Chilean office of Pezo von Ellrichshausen has for years worked with the relationship between structure and the architectural space. Working mostly in smaller scales, their architecture can nevertheless

Fig. 4 The apartment building in 51, Rue Raynouard, Paris (1932) by architect Auguste Perret. Parisian flavour on the exterior and a truly individual inner space of great architectural significance. Photo; Wikimedia Commons/Fred Romero

[4] Among Norwegian architects who are deeply concerned about the role of structures in architecture on a general basis can be mentioned Arne Henriksen, Carl-Viggo Hølmebakk, and Jensen & Skodvin. "What you get today is a kind of stage design. A world of buildings that are just surfaces", says Arne Henriksen. See interview by Einar Bjarki Malmquist in Arkitektur N, No 2, 2012.

Fig. 5 Residential building in Le Havre by Auguste Perret. Photo; BNS

inspire design of multistory buildings for housing as well as for commercial purposes. Likewise, the Tamedia building in Zurich by Shigeru Ban stands as a particularly refined example of the contemporary interest in wood, glulam as well as CLT. To mention just a few, one could also include a second Zurich based office, that of E2A Architects by Eckert and Eckert, who has designed many interesting buildings that take on a particular importance in our context, as well as the Danish office of Lundgaard og Tranberg Arkitekter who continuously delivers well-structured office buildings and apartment buildings of impressive quality.

Nevertheless, the vast majority of buildings of this type are mediocre when it comes to the particular qualities we call for here, not least when we look at the Norwegian scene. For too long, structures for multistory buildings, which probably represent the most common building type in the world, have been seen by architects and developers alike as a necessary tool for construction, and not as a potent medium to generate spatial qualities and to inspire architectural articulation. There are possibly many reasons for this, and cost is just one of them. In later years the seafront of central Oslo has been revitalized by many new office buildings and residential buildings, notably the row of multistory buildings called Barcode. Distinctly different as they appear on the outside with various elaborate facade designs, if stripped of their cladding all would look the same. The structures are virtually all of the same type, a standard, efficient framework that can accommodate all functions and all exterior expressions, but otherwise take no part in the architectural design. These buildings, however, are situated in Norway's most expensive area and houses Norway's most wealthy companies. And yet, no effort is made to create interior spaces with more convincing and lasting qualities, and qualities that relate to the tectonic aspects of architecture represent a likely opportunity. This is probably a matter of attitude, capability and financial will. When cost is seen purely in a short-term perspective architecture can be denied those qualities, and long-term architectural value as well as financial value can both be lost.

As we have seen, there are numerous examples of single accomplishments within this building category when it comes to activating the structure architecturally, and that by doing so one has been able to generate architectural qualities not likely to be achieved by other means. Even so and judging from the history of modern architecture and from what we can see around us daily, one can claim that, on the whole, there is *a lack of an architecturally relevant structural tradition in the design of multistory buildings*.

Strategies for a structural/spatial design

To get a grip on the present design problems relating to the structure/space relationship, and also to introduce a strategy for a systematic investigation in an academic context, a structural variable is introduced. Studies of various structure/space relationships for multistory buildings are carried out by identifying and describing a few *structural types*, organised according to their *vertical* load-bearing configuration. It is not surprising that focus is directed to vertical elements since the clear span of floor structures for most multistory buildings is relatively small. The structural types in question are well-known, but they act here as design parameters to give both architectural and structural design a particular direction, enabling a systematic design approach and design evaluation. The structural types represent different ways of coping with loads, but also different ways of generating architectural spaces that have dissimilar visual and functional properties.

Three structural type forms are identified: These are *line structural elements* like beams, struts, ties, arches and columns, where the latter element is perhaps of highest consequence in this context; *surface structural elements*

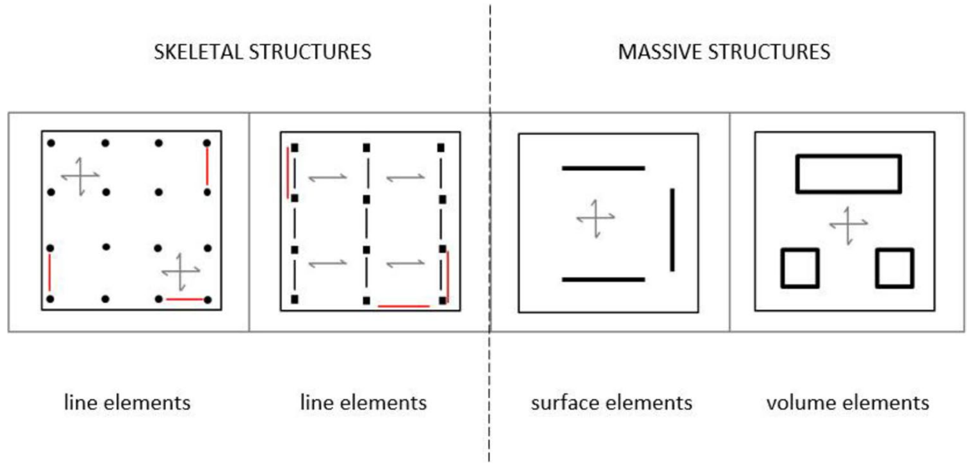

Fig. 6 Four plan variations of vertical structural element arrangements of which there are *three basic type forms*, are shown. Those are *line structural elements* (which appear in two variants; without beams and with beams), *surface structural elements*, and *volume structural elements.* Numerous variations of these fundamental types are possible. It should be noted that these are merely schematic suggestions and that they do not reflect all there is to a real-life building plan. Dots indicate column positions and thick black lines indicate the locations of loadbearing walls. Thin black lines between the dots (columns) represent beams, and arrows point out the spanning direction of the floor structure. Where no beams are indicated by straight lines between columns, the horizontal (floor) structure is being thought of as a flat slab of reinforced concrete, or even of CLT floor elements. Where arrows cross, two-way action of the floor slab is being suggested. Red lines represent the need for some sort of lateral bracing in the vertical structural system, which in the case of beam/column proposals may include the forming of rigid frames. (Partly quoted from Sandaker, Eggen, Cruvellier [5]; *The Structural Basis of Architecture, 3rd edition*. Routledge 2019)

that include slabs, vaults, shells, wall-beams (plates) and walls, of which wall-beams and walls are particularly relevant; and finally, *volume structural elements* like shafts and cores (see Fig. 6). The last type form might perhaps not really deserve to feature as a separate structural category, but it nevertheless points out the particular characteristics associated with walls that close onto themselves and form hollow spaces of prismatic shapes, or even including the formation of organically shaped volumes of curving or undulating surfaces. If elements like these are brought continuously through the whole building height as open shafts, they form the well-known cores that are commonly used in multistory buildings as stairwells and elevator shafts, and for stability/bracing. If closed off at each floor slab, such elements may provide spaces at each floor for different uses. The side walls of these continuous structural elements can be perforated and opened up to a smaller or larger degree to admit light and access. A volume structural element like this will have significant loadbearing capacity while at the same time will be offering distinct, spatial qualities related to the creation of positive and negative architectural spaces.

And not least; *hybrid* systems making use of a combination of line, surface and volume structural elements are studied. Such combinations represent far more structural variants and additional spatial expressions than is the case for a pure application of only one type. Besides, the issues of vertical infrastructure in the form of stairs and lifts, and not to forget the building's stability, make walled systems organized as structural cores seem practically unavoidable.

Since both line and surface structural elements can be curved, folded, and tilted, walls can be opened in different ways, and all three type forms can be organized in numerous ways in a building plan and building section, the variety of structure/space configurations are literally unlimited. The studies thus open up for new insight into the complex relationships of structures and spaces.

To clarify the direction and aim of the studies, we may formulate three research/design questions:

- Will a deliberate thinking, seeing, and treating of structural elements and structural assemblies *as architectural agencies* contribute to advancing certain qualities that relate to the program and to the experience of the space?[5]
- If the above is really the case; what might those qualities be?[6]
- To what extent will a categorization according to basic *structural types* (line, surface, and volume structural ele-

[5] This ambition is deliberately set up against the too common approach where the structure forms a rack or a scaffold, a nondescript framework, within which architectural spaces are situated and supported.

[6] We tend to think here of “qualities” as characteristics that have certain virtues, i.e., that “spatial qualities” denote some features of the architectural space that are thought of as being desirable.

ments) contribute to clarify the spatial potential and the qualities inherent in the different structural strategies?

A continued design process that focuses on these issues may provide some answers.

Some spatial characteristics of the different structural types

Without opening up a lengthy ideological discussion of the idea of structure systems as generators of architectural form and space, we state for our purposes that structures do have a wider importance in architecture than simply that of carrying and resisting loads. This position implies that the structures we consider manifest themselves, not necessarily on the exterior of a building, but at least in the interior spaces. They are "exposed structures". This is in fact an important precondition for the studies we do: if columns are hidden in walls or other secondary building elements, they are not just brought out of view, but it also declares those columns to be architecturally unimportant in any other sense than to hold a building up. Admittedly, hidden structures may well be instrumental for the possibility of making particular, architectural forms and spaces, but such structures are not directly available for the *experience* of those spaces, forms and of the material textures that make up the surfaces. In such cases, both the visual and tactile experiences linked to those fundamental tectonic elements are denied us. The central idea of our investigation, then, has been to identify architectural qualities that can be said to emerge from a more architecturally conscious and active use of the load-bearing system for space-making, and to examine the results of this idea.

We may observe some very fundamental properties or qualities that are easily associated with the three different structural strategies that we have identified and named as types. Line structural elements like columns form *skeletal structures*, or frames, while the surface and volume elements form what can be termed *massive structures* in the form of walls or wall beams, and shafts/cores.[7] We can experience the differences between skeletal and massive structures in terms of basic spatial properties that are associated with them. Let us use as examples the spaces we find in the two well-known houses of Palladio's Villa Foscari from 1560 and Mies van der Rohe's modernist house the Tugendhat from 1930. In the former there is an intimate relationship between the structure and the space in the sense that load-bearing walls enclose and delimit space (see Fig. 7). This is part of the tradition represented by brick and stone buildings. In the latter example where steel columns do the work of walls, there is a much looser connection between the solid and the void, the structure and the space (see Figs. 8 and 9). Here space "floats" in-between and around the columns, a particular quality introduced by the modernist concept of the "free plan".

Of course, as an intermediate position between wall systems that close off a space and columns that open up, load-bearing walls need not be of the former, traditional type. Mies also designed a project for a country house in brick (1923), in which load-bearing walls do not meet to encircle space, but are organized in parallel or perpendicular to one another without touching. While still suggesting room zones and sightlines, movement and spatial expansion are much freer than in the traditional house.

The third type of basic structural strategies that is explored, namely the use of 3D units, or volume elements, as support may not be a very common strategy. Nevertheless,

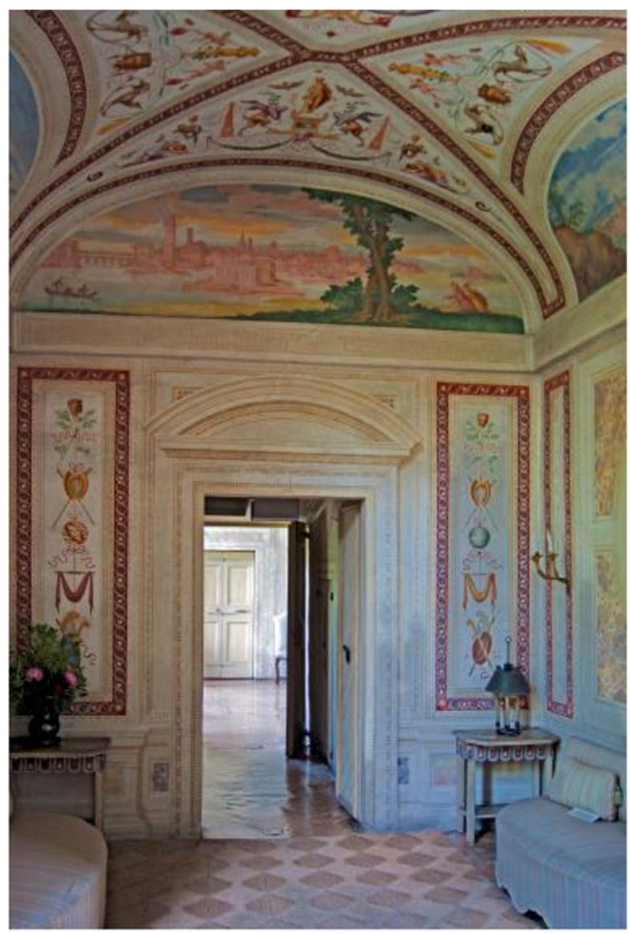

Fig. 7 The Villa Foscari is an example of the massive structure of walls that establish a tight relationship with the space they enclose. Photo; Wikimedia Commons/Didier Descouens

[7] Architectural theorist and historian Christian Norberg-Schulz described these two basic systems as "skeleton systems" which are "defined through the distinction of bounding and supporting elements ", and "massive systems" where elements "are simultaneously bounding and supporting". Norberg-Schulz [3], p. 163, 164.

Fig. 8 The modernist Tugendhat House shows a skeletal system of columns that enable space to "float" unrestricted in-between. Photo; Wikimedia Commons/User: Simonma

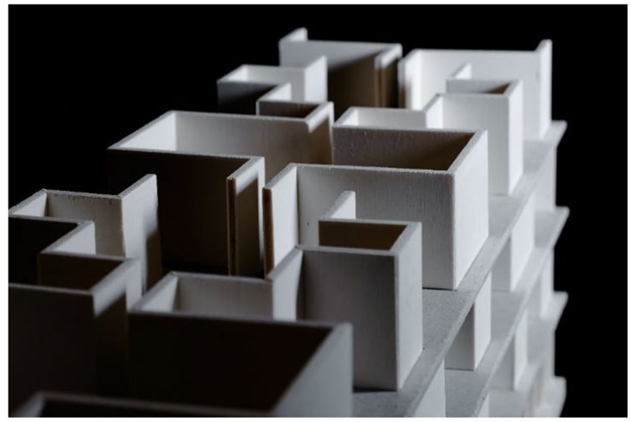

Fig. 10 Corrugating or folding walls form almost box-like structural units that create introvert spaces as well as intermediate, open spaces. Studies by 2nd year students at AHO, 2019. Photos; Christian Magnus Tømmeraas Berg

this idea introduces spatial capacities and qualities in terms of the different potential functions and spatial characters that emerge *within* and *in-between* these structural volumes. In the interior space formed between two floor slabs, 3D units in the form of rectangular prisms will appear like "boxes" (see Fig. 10). A regular or an irregular stacking of such structural/spatial units into open or closed shafts offers a strategy for very varied application. These volume structural units are seen to be opened with a number and size of openings that are fit for their use, while maintaining their load-bearing function. Hence, the architectural spaces generated are to a larger or lesser degree closed rooms in the shapes of prismatic boxes or cylinders, or organically shaped, but also in the form of the intermediate space that "flows" in-between and around those volume structures. This strategy may also offer vertically and diagonally oriented spatial sequences, in addition to the horizontal. The spatial character of the result will to a large degree be determined by the size of the volumes compared to the size of the overall space, and of their proximity and shape. The resulting structural plan may have something of the character of a city plan where the structural units form the "houses" and the space between them act as "streets".[8]

Fig. 9 The spatial openness of a structural strategy based on line structural elements, i.e. columns, permits large, continuous floor areas that may, or may not, be partitioned by non-loadbearing walls

By working with massive structures in the form of surface structures (walls) or in the form of volume structures (shafts/cores appearing as "boxes", or even as more organically shaped volumes), some additional spatial/physical aspects are introduced. Firstly, these structural types bring in, not only the presence of visual weight, but also of physical mass. This is particularly the case when using reinforced concrete as a structural material, in which case the *thermal mass* associated with such relatively heavy structural elements is of significant interest for the balance of heating and cooling of the interior spaces. And secondly; the nature of their surfaces and their shape or orientation heavily influence physical and experiential properties like room acoustics and sound insulation, depending on the chosen material's absorption properties and its weight. Thirdly, the use of walled systems strongly suggests their application as primary stability measures for the building. In massive structure systems like these, then, some performance criteria other than pure load-bearing

[8] A "classic" example of an irregular stacking of structural boxes with no intermediate slabs is the Habitat 67 in Montreal by architect Moshe Safdie. Here, prefabricated modules that are both structural and spatial are stacked into a multistory arrangement, while also retaining the individual atmosphere of a suburban home.

Fig. 11 A preliminary, purely structural study of a multistory building that exploits different structural typologies in a hybrid composition. AHO/Multistory Building (MSB), 2018. Project and model by; Johann Sigurd Ruud, Maja Andresen Osberg. Photo; Joar Tjetland

Fig. 12 This model employs a distinct box-like strategy in the lower stories. AHO/Multistory Building (MSB), 2018. Project and model by; Are Hagen, Kaja Strand Ellingsen. Photo; Joar Tjetland

seems quite possible to activate, some of which will also operate on our senses.

Hybrid structural strategies that activate the whole range of structural elements offer functional, structural and spatial possibilities where the potential of both the skeleton and the massive structure can be exploited (see Figs. 11 and 12). This strategy in particular invites variations across the plan and between different stories and will be able to bestow a building with numerous alternatives for being used and being experienced.

Typology studies as a method for structural/spatial investigation

The idea behind a thinking in terms of structural types is simply to put names on characteristic and basic structural variants. This serves two purposes. One is to increase architects' and engineers' awareness of structural forms and strategies and their spatial and aesthetic potential. The second is to suggest a direction for the choice of a structural strategy that is of architectural interest. Against the idea of a design based on structural typologies, however, one might claim that doing design "with your hands tied" is not a good thing. One might contradict the idea of offering a diagram of structural types, and object that putting structural options into categories restricts the free thought and creativity and may act against its purpose. Potentially, it could be seen as a risk that concepts based on such a design strategy might lead to results that are of inferior quality compared with those that follow from a completely "free" design.

Yet, in our search for better architectural solutions to the problems relating to space/structure-relationships than those that present an uncommitted use of hidden technical/economic frameworks, we suggest that a conscious use of structural form-types, however in diagrammatic forms, may be of use as inspirations and models. Implicitly, we acknowledge that the measurable requirements that apply to structures also leave a choice for the architect and engineer to make. The question is in what way design decisions like these are made. According to the architect and theorist Alan Colquhoun choices also of "truly quantifiable criteria" has in modern architecture generally been "conceived of as based on intuition working in a cultural vacuum".[9] Intuition, however, does not come about by itself, and Colquhoun, referring to Tomas Maldonado, supports the idea that "the area of pure intuition must be based on a knowledge of past

9 Colquhoun [1], 1981 (1986), p. 47.

solutions applied to related problems, and that creation is a process of adapting forms derived either from past needs or from past aesthetic theories to the needs of the present”.[10] This suggests a thinking in terms of some kind of typological model.

Where does this leave the impression that structural form often results from the creative meeting between load-bearing necessities, the organization of a building plan and section, and the kind of space that is intended? This still holds true, but the question about the way design decisions on structures are made, remains. Load-bearing as such is a necessity, but in what way adequate load-bearing is provided is wide open for numerous choices, both regarding span lengths and structural element types and shapes, and their organization. *The important thing to acknowledge is that a moderate use of a structural typology does not exclude a creative application of structural form which may also offer a specific solution to a particular architectural problem.* One reason for this is that architecturally “active” structures will, almost per definition, intrinsically be a part of the architectural space, and form a relationship with issues concerning functional use and spatial character (see Fig. 13). Structure and space are in such cases mutually connected: a choice of structural strategy is also a choice of certain spatial properties. And vice versa. Introducing a vocabulary of structural options arranged as type-forms may therefore help both to bring about a particular functional space organization, as well as certain intended spatial properties and architectural ambience.

Moreover, to be able to be as wide-ranging as possible in our search for structural solutions that may also offer spatial qualities, we need to ask a couple of basic questions: what structural options are available for the architecture of multistory buildings, and what are the structural and spatial implications of those? Also, a study of the kind we engage in cannot set every possible structural configuration in motion at the same time. Such a strategy would prevent any form of systematization of observations, and we would be hard put to find interesting solutions that might be of *general value*. All designs would be specific and hence impossible to categorize and communicate. That is a main difference between doing the structural and architectural design of a specific building, and what we try to do, namely, to acquire a study material that consists of numerous buildings designed within an academically modelled framework where certain design parameters are, if not entirely fixed, certainly suggested. When variations in the study material are brought about by differences in building site and program, while at the same time some parameters concerning structural strategies are kept unchanged, we should be able to learn something of general value from what we observe, and to

Fig. 13 A preliminary, purely structural study of a multistory building that investigates the structural and spatial potential of wall-beams (plates). AHO/Multistory Building (MSB), 2019. Project and model by; Banin Syed and Alvar Aronija

do an evaluation of the way certain structures relate to the different spaces. This is part of the explanation for arranging structural options in certain categories, or types, of the kinds that are described above. One might also comment that the types to a certain degree should be seen as loose patterns or templates, so that "walls" with openings may nevertheless stand out as more or less compact frameworks of different kinds, or maybe with large cut-outs in the form of arches or some other geometry. And "skeletal" structures may become so dense that they for all purposes appear as a surface.

The way this structural typology is identified is important. Commonly, it seems appropriate to categorize structures according to how they behave: it is the load/form/force relationship that is most often brought up for scrutiny in a study of structural components and assemblies. This is not the case here. Since our concern is architecture, and specifically structural/spatial relationships for multistory buildings;

[10] Ibid.,1981 (1986), p. 47.

with our identification of certain basic structural types, we do instead *an architectural classification of structural options, rather than a mechanical classification* of *structural behaviour*. This means that besides planning for adequate structural stability, strength and stiffness, our study projects investigate what possible spatial qualities the different structural strategies may seem to hold.

Architectural ambitions

To guide the design processes and to direct it towards certain aims that we hope to achieve, partly by activating structural strategies as described above, we may formulate some predominant architectural concerns and ambitions. On an overarching level we wish to address issues concerning architectural spaces and structures by pursuing *beauty, appropriate flexibility, durability, and sustainability*. It will quickly be realized though, that these ambitions are strongly interconnected, and that they come in addition to the more immediate concerns for structural functionality and stability.

Firstly, we claim that a durable building with prospects for a long life is a sustainable building. If we can build in such a way that people can, and would wish to, use it for generations, we can begin to suggest that its construction to a large degree has been environmentally friendly, almost irrespective of the short-term carbon footprint that can be associated with the specific structural material used. Hence, the important question is: how can we best plan a building in such a way that it copes with changes of different kinds and survives through a long time? And what has the building structure to do with it? At this point we need to ask what reasons are typically given for the dismantling of numerous buildings after a few decades in operation, buildings that seemingly are highly functional and operative. The prime mover, of course, is money. If an investor decides that more is gained financially by tearing a building down and raising a new one, this will happen, unless there is some law to prevent it, or that the owners should realize that the existing building possesses remarkable qualities that would lead to serious public loss, or the loss of company reputation, to destroy. To counteract premature disassembling of a building from financial reasons, then, only one strategy might work, although the hope is feeble, and that is to build high quality architecture in the first place.

A second reason given to replace an existing building with a new one is an alleged lack of *flexibility*, real or not real. There is in buildings of the type that we discuss a need for a certain flexibility, operating on different levels. One is that the building should be able to be adapted to the different and shifting requirements of owners or users, linked to its program. Common transformations into new use may be from office to housing, or the other way around. On another level of flexibility is the necessity to cope with changes in technical installations over time, commonly to accommodate larger ducts and machines connected with requirements for ventilation, heating, and cooling. Usually, this means to be able to provide for larger technical floor areas and larger story heights.

What will this mean for the choice of a structural strategy? Activating the structure system architecturally means that structural elements often acquire a visual and physical presence that they may not have in more pragmatic structures, hidden as the latter often are in partition walls and exterior climate barriers in multistory buildings. Architecturally "active" structures are seen and felt and will influence on space and function in some way or another. They will tend to be context dependent, and site or function specific, relating unmistakably to the architectural program and to certain architectural ideas and ambitions. Some might see this to go against a requirement for flexibility, the commonly shared concern that a building throughout its life should have reasonably good chances of being reused by new proprietaries and with new functional and technical equipment. Important questions can be raised, though: How are flexible buildings designed? What characterizes flexible spaces?[11] Among the quantifiable factors generally considered to affect flexibility are floor heights, spans, and floor loads. Flexible spaces are thought to be more feasible if all three parameters are generously dimensioned. Going purely for this strategy, however, might result in generic spaces of little interest and frequently of low quality. One may therefore ask; to what degree is *generality* really a precondition for the probability of reuse? And is flexibility the sole measure for a building hoping to have a long life? Could it be that some sort of bespoke design for a specific program might also inspire future, and different use, because people and businesses may be attracted to something of architectural interest and character, and that the structures designed to accommodate that particularity may also prove to fit well for a completely different program? Such questions have been of great interest to us and have been important in our discussions with students during their design processes.[12] No definite answers

[11] In their article «Building Flexibility Management», Arto Saari and Pekka Heikkilä [4] suggest that a building may have three types of flexibility; *service flexibility* that is considered to be especially important for users, and may typically be improved by movable partitions and adjustable ventilation; *modifiability* that may be improved by a "loose" dimensioning of building services and system walls; and *long-term adaptability* which refers to the building's ability to be adapted to unknown activities and uses, especially important for property owners.

[12] An observation by student Ingeborg Svalheim (MSB/2018) on her own project: «It is possible that one risks losing a series of important architectural qualities by seeking flexibility – just because it could one day be changed. When the starting point is no longer flexibility, occasion for architectonic attention might possibly be more natural. And with that, one needs perhaps not to be afraid of designing particular rooms, because the room – and its size – in itself has a quality and, regardlessly, a potential" (translated from Norwegian).

are offered, though, only a hypothesis: more importantly, probably, than the open generality of large-spanning structure systems displayed by so many nondescript buildings, is a building of high architectural quality for the prospects of a building to last for a long time. And that quality could be provided by consciously choosing a structural strategy that enhances the character and quality of the architectural space.

Should we instead, inspired by a study by Saari and Heikkilä [4], aspire to pursue an "appropriate flexibility", and acknowledge that a structural strategy that allows a complete, seamless and almost dynamic transformation between programs, while maintaining both a spatially and structurally optimized solution, is not a realistic aim?[13] Do large spaces really need to be free from structural elements? When is a column or a load-bearing wall a hindrance and not an architectural asset? There are obviously no fixed answers to these questions, but the main thing is to bring them up, to be aware of the issue, so that the design of high-quality architecture with a distinct character also regarding the structure/space relationship is not automatically seen as a limitation that prevents a necessary, but appropriate flexibility.

Behind the ambition to contribute to "architectural quality" hides the concept of *beauty*. We might approach that concept by simply pointing to the sense of well-being that relates to our experience of certain spaces and forms we encounter. In the architecture that we consider structural elements and whole structural arrangements are tightly woven together with a large array of elements for other purposes and are inseparable from the spaces that they help to create. This means that an aesthetic appraisal needs to consider, not only the structure seen as lines, proportions, shapes, and material textures, and assessed as tools for strength, stiffness and stability, but also that those very same attributes should be seen in the particular spatial context they are parts of, including how they relate to daylight.

There is no room to elaborate on this topic here, other than to say that the aesthetic experience is comprised of both feeling and thought, as Roger Scruton [8] has shown: while it is partly an experience of the senses, feelings are intellectually processed in aesthetics, and this processing is part of the aesthetic experience.[14] Hence, aesthetic words or terms like "beauty" work fine as compressed expressions of evaluations of e.g. student projects, but need to be followed by a more reasoned argumentation for the visual impressions we have. This reasoned argumentation might enable the student to see what we see, and therefore also to experience what we experience, namely the aesthetic qualities of a project, or the lack thereof.[15]

[13] Saari and Heikkilä [4] also suggest a new indicator, the flexibility degree, which may be used to quantify flexibility. Ibid., 2008, p. 240.

[14] This is thoroughly discussed by Roger Scruton [8], in his book from 1979.

[15] A short discussion of the aesthetics of structures is offered in [7], where viewpoints elaborated in [6], are summarized.

Design studies of multistory buildings

To investigate by help of architectural design this complex problem area of the relationship between architectural quality, structural strategies, spatial flexibility, and sustainability, master courses on "Multistory Buildings" are held at AHO on a yearly basis. In these courses students design multistory buildings for residential and/or commercial purposes on different sites in the Oslo area. For these buildings, guidelines

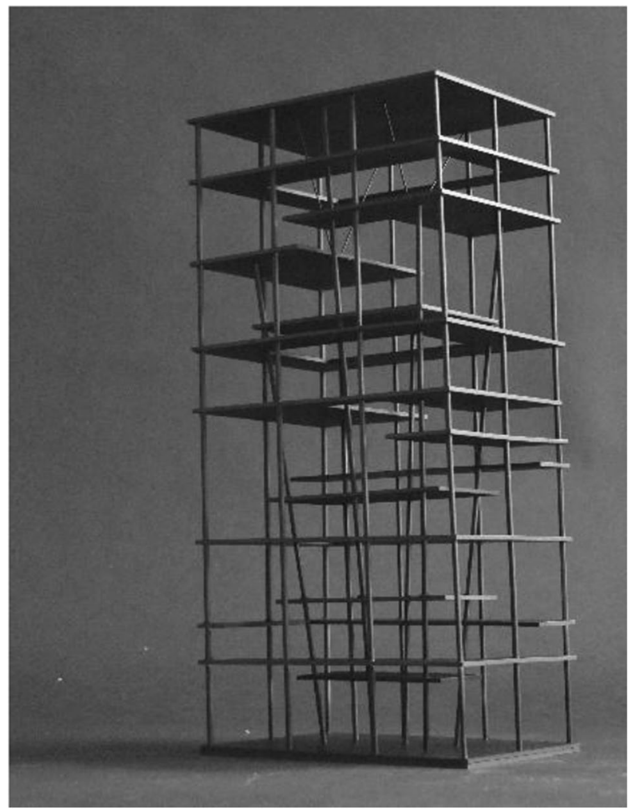

Fig. 14 Line structural elements. Project and model by Åsmund Skeie and Endre Hareide Hallre. Photo; Joar Tjetland. Figures 14, 15, and 16 show three examples from the preliminary, purely structural studies carried out in a one-week exercise seeking to train the students' skills in designing structural systems for multistory buildings. Before starting up with the main design, smaller assignments are formulated to act as "ouvertures" to open the field and to selectively get the students in a right frame of mind. Among these is a one-week exercise to propose a structural system for a building of up to 42 m height with a ground plan measuring 12 by 18 m, containing more or less twelve stories. No functional program is defined, but all students are assigned one of four structural strategies of either the three type forms of line, surface or box structure, or a hybrid variant. Its main purpose is to train their skills in designing credible, but interesting, structural systems for this building type and to cultivate an awareness of the relationships that exist between structural form and its spatial implications. New ways of looking at structural systems emerge during the process, enabled by the requirement to think in clear structural types. While successful in its own right and fulfilling its structural intention, this exercise, in the absence of a program, is not intended to get to the core of the problem in all of its complexities. On the contrary, that is the aim of the main assignment

Fig. 15 Surface elements as walls with large cut-outs. Project and model by Edward G. Wahlström Nesse and Maria Højgaard Molden. Photo; Joar Tjetland

Fig. 16 Volume elements in the form of "boxes". Project and model by Hakon Helseth and Mathilde Cecilie Lobben. Photo; Joar Tjetland

on structural types are offered, but the decision on structural strategy may or may not be left to the student to make. It becomes quite clear, however, that students bring with them the insight acquired from the preliminary exercise exemplified here, to the main assignment of designing a multistory building in all its complexity (see Figs. 14, 15 and 16). We will bring up but a few projects from the main assignment for presentation and discussion:

Project for a residential building in solid wood (MSB 2017) by Ola Mo and Peder Pili Strand

In this project by Ola Mo and Peder Pili Strand, the authors have sought to reduce unnecessary, dead space as much as possible and have located vertical transport, entrances to the flats, and bathrooms in the core area of the floor plan (see Figs. 17, 18, 19, 20 and 21). In a typical plan, kitchens are placed in the corner rooms. All these rooms are of a sort which is not interchangeable for other uses. All other floor areas are located along the perimeter and also have good daylight conditions. They are all the same size and can function as bedrooms, working spaces, or living rooms according to the needs of the occupant. Rooms can be connected by openings in the walls between them.

The solid wood structure (CLT) consists of load-bearing wall panels, floor slabs, and glulam ring beams. The walls

Fig. 17 Entrance to the social housing, residential building in solid wood

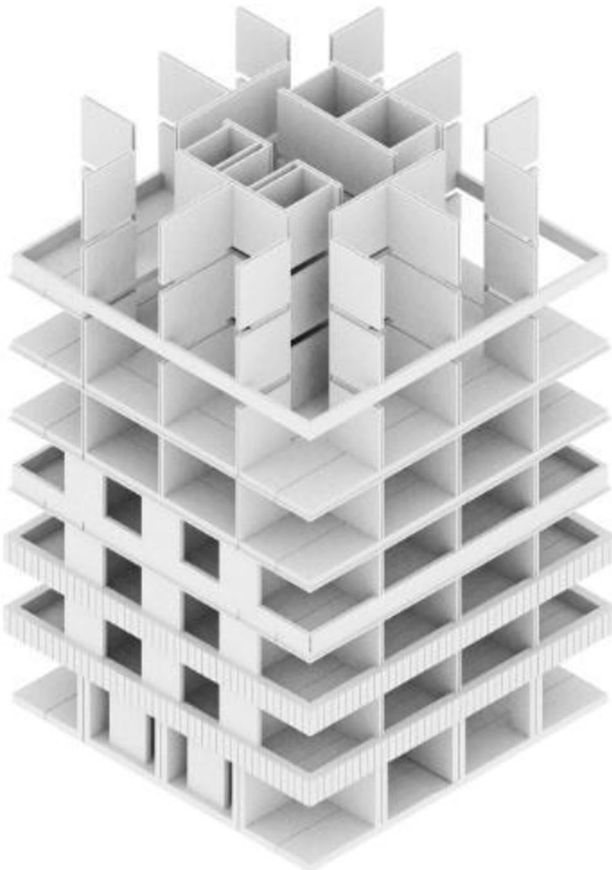

Fig. 18 Axonometric drawing of the structure system

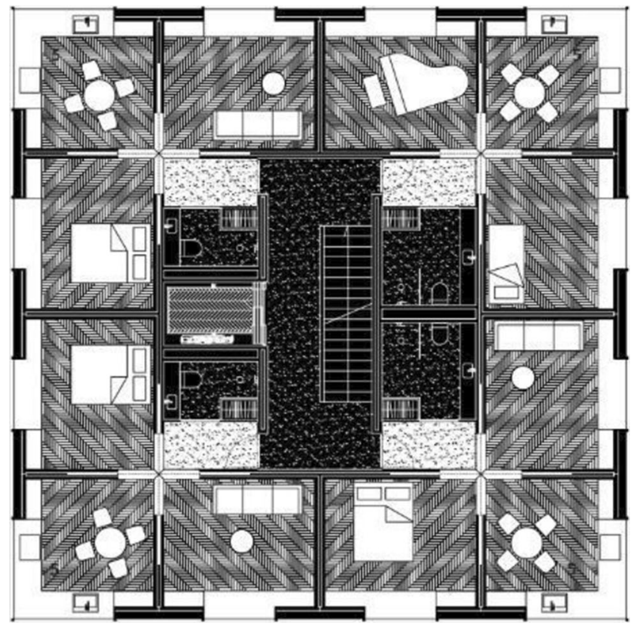

Fig. 20 Typical floor plan

are oriented perpendicularly to the facade. This is to be able to bring as much light as possible into the plan. Since most rooms in principle are accessible from the core area, the strategy of organizing the plan with a number of equal room units leads to considerable flexibility: small flats and larger flats can all be accommodated, and can be varied from story to story, or changed over time. The project shows an

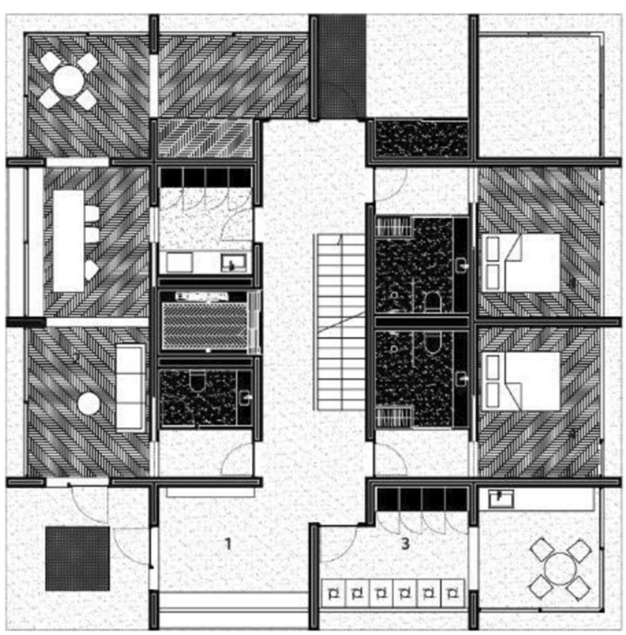

Fig. 19 Ground floor plan

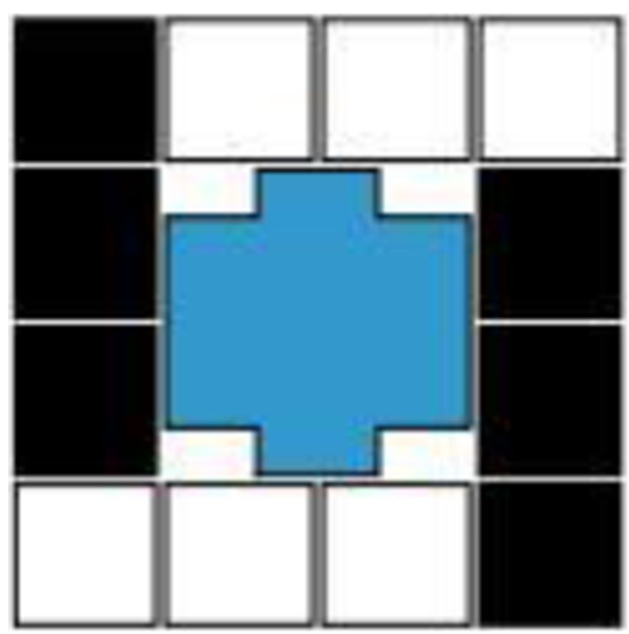

Fig. 21 Diagram of possible permutations of number and size of flats. Here is shown a variant with four flats of about the same size

interesting solution to the generality vs. particularity-problem in the way it addresses the question of flexibility. It is also a fascinating example of the application of a structural strategy that employs surface structural elements in the form of wall panels in wood to establish and express architectural spaces.

"Generality as preservation", a multifunctional building structure (MSB 2017) by Oda Frøyen Nybø and Ingeborg Svalheim

"After a long time our building will become a ruin. Our needs change with time, and some day there will be another architect standing over our building trying to do something new with it. What should be prioritized when an architect meets an old building? The importance of keeping a building's identity is present. One can think of a building's identity as DNA. What can be removed, and what have to be preserved? We want to make a structure where we try to be precise about what is permanent and solid, and what is temporary and easy to change. Maybe this strategy can be a new attitude to preservation and sustainability?"

Oda Frøyen Nybø's and Ingeborg Svalheim's main goal has been to study and develop a building structure that emphasizes generality and flexibility. The building should be able to accommodate a change between different programs over time. Their focus has been on elaborating a loadbearing structure system based on a relatively small spatial unit. Instead of making a program-based building containing a huge variety of room sizes and corridors, their start-up was to develop only one, basic room size and shape (see Figs. 22, 23, 24, 25, 26 and 27). After testing different sizes and shapes they decided on a room of (3.5 × 3.5 × 3.5) m.

The proposal for organizing rooms on any general floor level was adapted to the actual plot and concluded with eight rooms on each side of a central communication area. The students chose to make the basic room unit from precast, vertical and horizontal concrete panels acting as walls and slabs, constituting the permanent structure of the building. The 2.7 m gap in the middle, meant for horizontal and vertical communication, is thought of as a flexible mid-zone. Adjacent rooms on both sides of the mid-zone can also be merged to make bigger rooms of 3.5 × 9.7 m floor area, or more. The temporary and changeable mid-zone can also be opened up vertically over several floors to make room for stairs, lifts, or even interior atriums. Or, in the extreme, the building can simply become two building volumes by emptying the mid-zone. The slabs in this zone are made of solid wood (CLT), a light stucture that is easier to remove than the more permanent, concrete structure. All building elements added to the concrete structure to make the building work are defined as temporary. These also include stairs, elevators, windows, doors, partition walls, bridges, balconies, and so on. All these additional elements are prefabricated and bolted to the concrete structure. The students' idea for such a high degree of prefabrication and well worked-out ways to join/dismantle (and rejoin) the temporary elements, is also an excellent input to the goal of a more circular economy in the future.

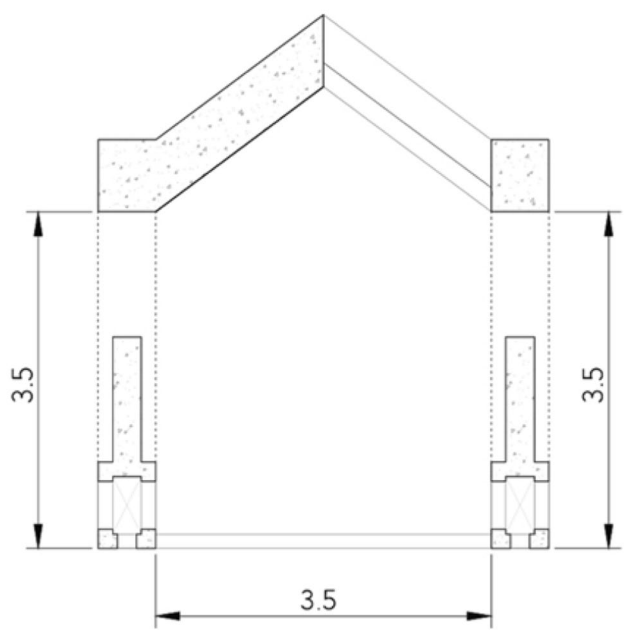

Fig. 22 The general room (diagram)

Fig. 23 The general room (actual)

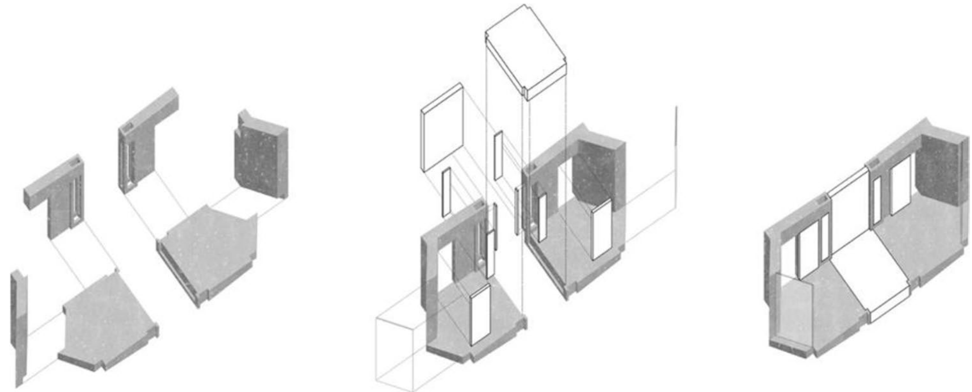

Fig. 24 From the left: permanent, temporary, permanent and temporary

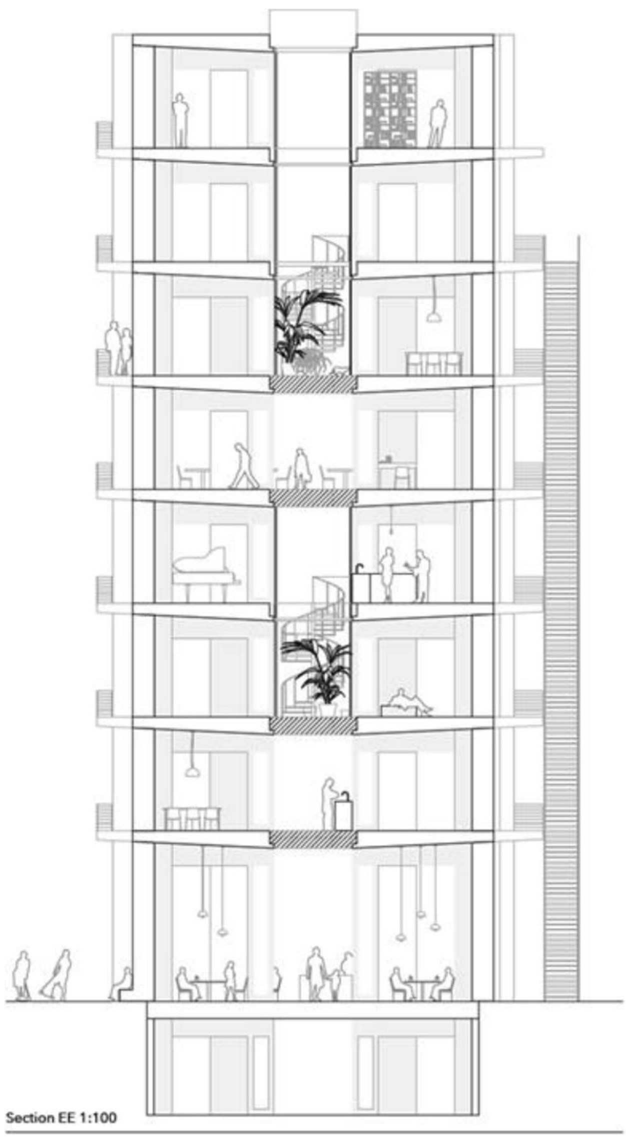

Fig. 25 Building section

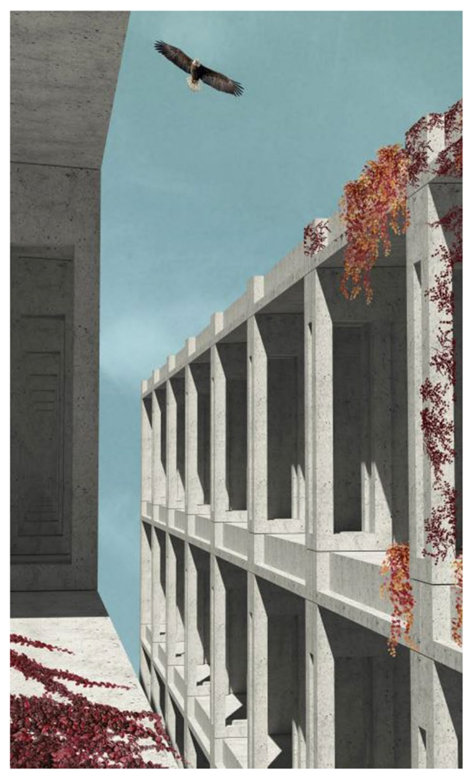

Fig. 26 View of the permanent building structure from an (empty) mid-zone for temporary and changeable communication

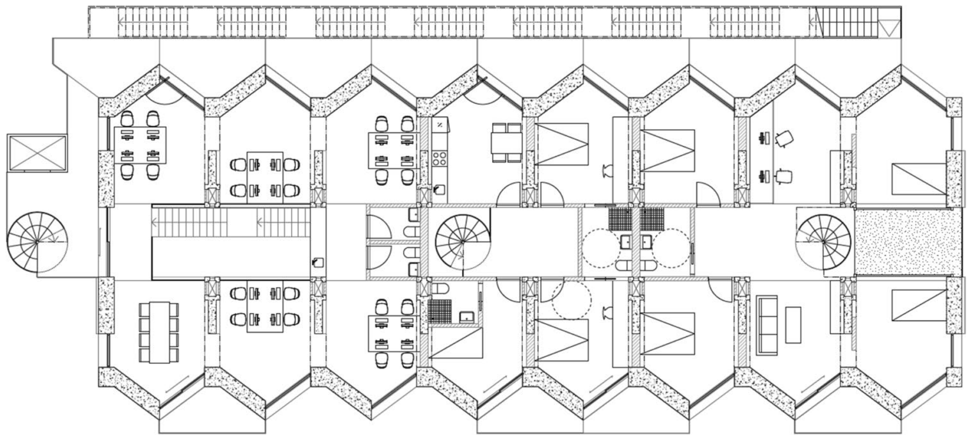

Fig. 27 The 3rd level plan shows part of 3 different programs; office space to the left, student housing in the middle and an apartment to the right

Fig. 28 Life in exterior rooms

"Room between rooms", a residential building in concrete (MSB 2018) by Kaja Strand Ellingsen and Maja Andresen Osberg

The idea of offering a certain generality of room size has been important in this project by Kaja Strand Ellingsen and Maja Andresen Osberg. The project investigates how rooms of a size between 10–20 m^2 may function for people being in different phases of life and having different needs and desires (see Figs. 28, 29, 30, 31, 32, 33, 34 and 35).

The design started with establishing a continuous structural wall that meandered along the perimeter, forming interior and exterior spaces around a fixed core. This helps to bring light of different characters deep into the plan. During the design process this wall

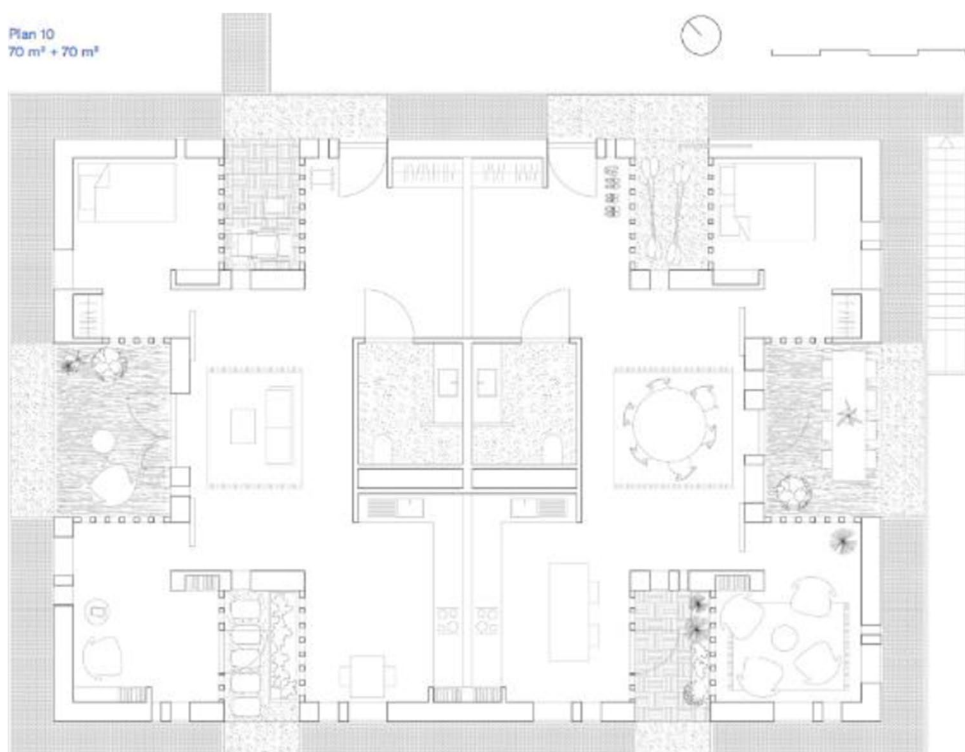

Fig. 29 An example of a plan with suggested use

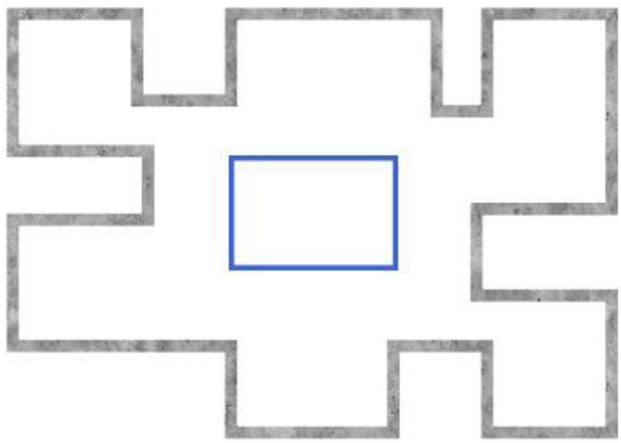

Fig. 30 The basic idea for a meandering, load-bearing wall

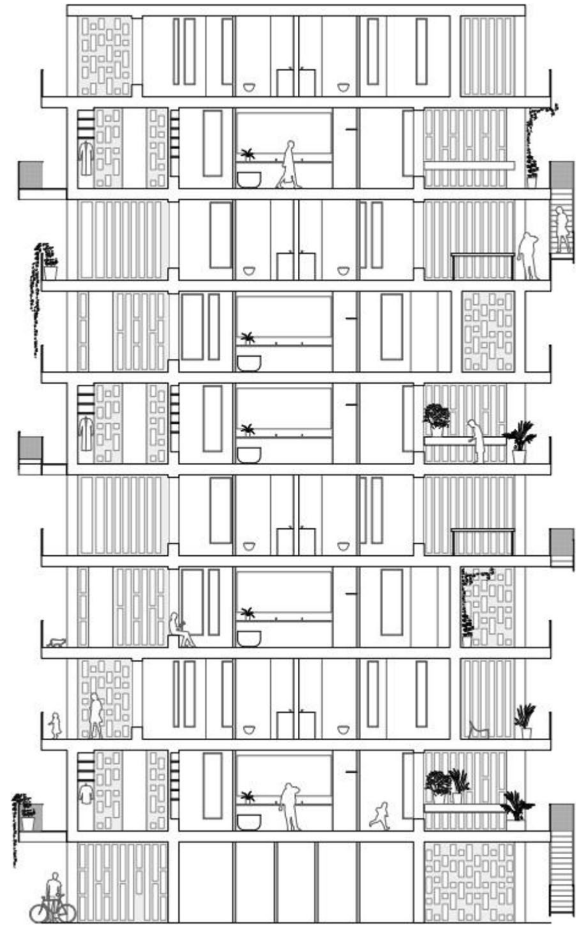

Fig. 32 Building section that indicate the spatial variations in the height of the building

developed into a system of wall panels with different perforations; some are completely closed, others are more open, and some lost their load-bearing function altogether and act purely as screens. Yet, all the different parts still make up a continuous, crinkled line. Moreover, to introduce different room configurations that have different characters a variable was introduced: there are four variations in wall patterns and openings of the continuous wall. These result in apartments of slightly dissimilar room shapes and ambience. The four variants each comprise a stack of four stories that support one another and are repeated in the height of the building.

Interior rooms can be utilized in various ways as living rooms, or bedrooms, or for dining or something else. They can be shut off by sliding doors to accommodate different needs. The central core is reserved for bathrooms and kitchen and is

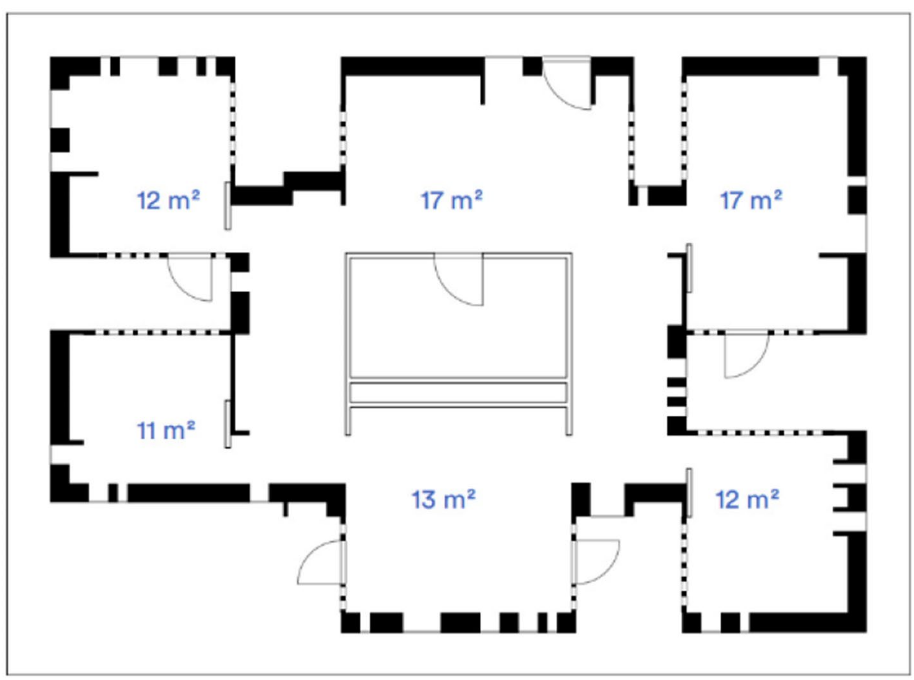

Fig. 31 The load-bearing wall as it developed into wall parts with different openings

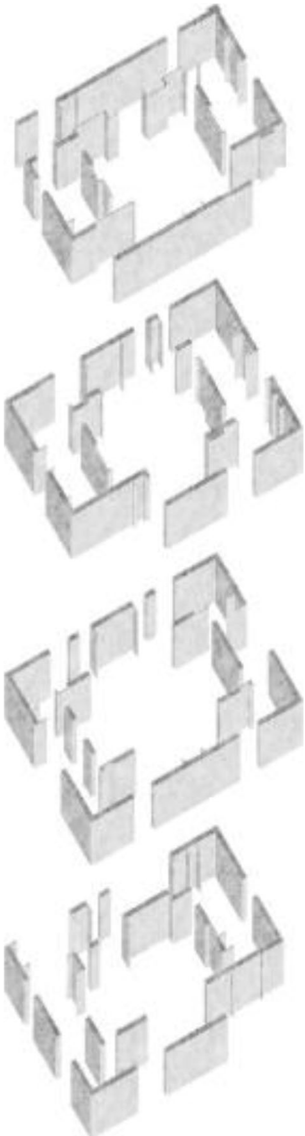

Fig. 33 Variations in the structure system to offer a variety of space and light conditions

Fig. 34 The structural variation in the building height results in a lively, non-repetitive elevation

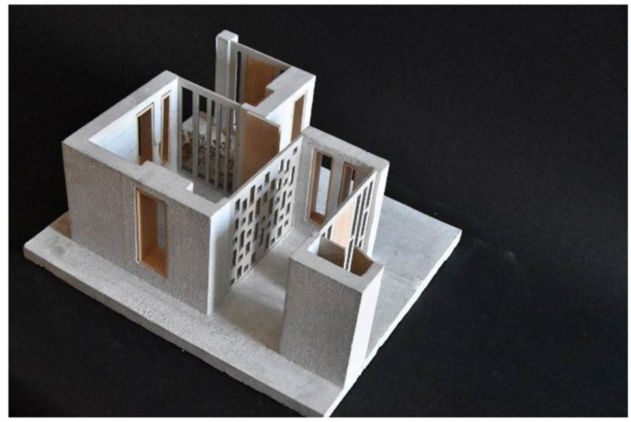

Fig. 35 Model of a part of the structural/spatial system

continuous throughout the building height. Exterior rooms are of different sizes and characters and are used for bicycle parking, or gardening, or as recreational areas. The qualities found in row-houses and in one-family houses are here offered in a residential, multistory building. However, to take full advantage of the daylight in both interior and exterior rooms a more generous room height would have been preferable.

This project is an interesting example of how a structural element, the wall, can act as a premise for the architectural concept. By letting this wall form rooms of a similar size a certain generality is introduced. And yet, the highly specific structural strategy gives the occupant a sense of spatial individuality while also maintaining a noticeable opportunity for altered use.

Project for a city house of mixed-use (MSB 2020) by Hanna Hovland Johanson and Hanna Højgaard Molden

A main idea for this project has been to accommodate in one building several activities of both a private and a public nature (see Figs. 36, 37, 38, 39, 40, 41 and 42). The authors

Fig. 36 The City House along the river, Oslo

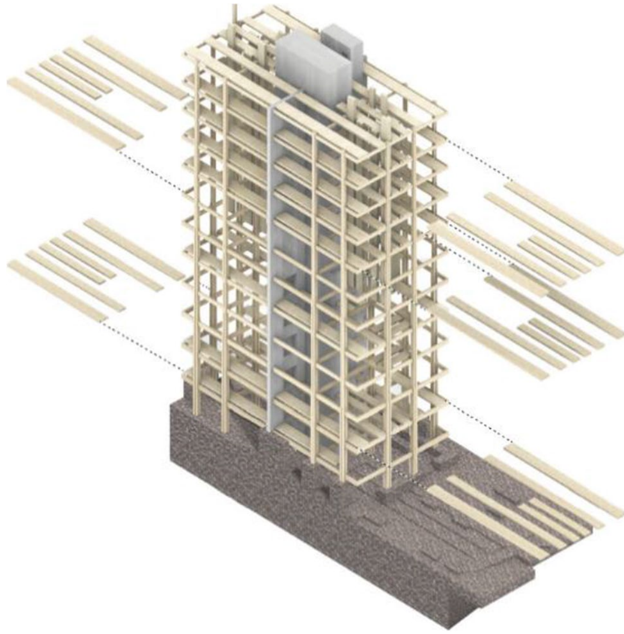

Fig. 37 The skeletal structure of columns, beams, and slabs, all in wood. A concrete core for vertical transportation and for bracing

Fig. 39 The workshop interior

Hanna Hovland Johanson and Hanna Højgaard Molden create rooms for an open workshop, a women's centre, and apartments of different sizes also containing communal, shared spaces. The public functions occupy the five lower floors. The intention, moreover, is to let different functions overlap and intertwine spatially to reflect the complexity of the surrounding city. The same idea of overlapping and intertwining is also used to create a concept for the structure. The columns and beams are themselves mutually intertwined and facilitate the interlocking of the different spaces while also are enabling various practical functions: columns split in four, but still work as one by help of suitable connections. Beams and sliding doors fit in between the column parts and connections are used to create shelves and benches.

To further provoke a linking of inhabitants' lives in the apartment areas shared facilities such as laundries, larger kitchens and living rooms, and outside galleries are provided. The design

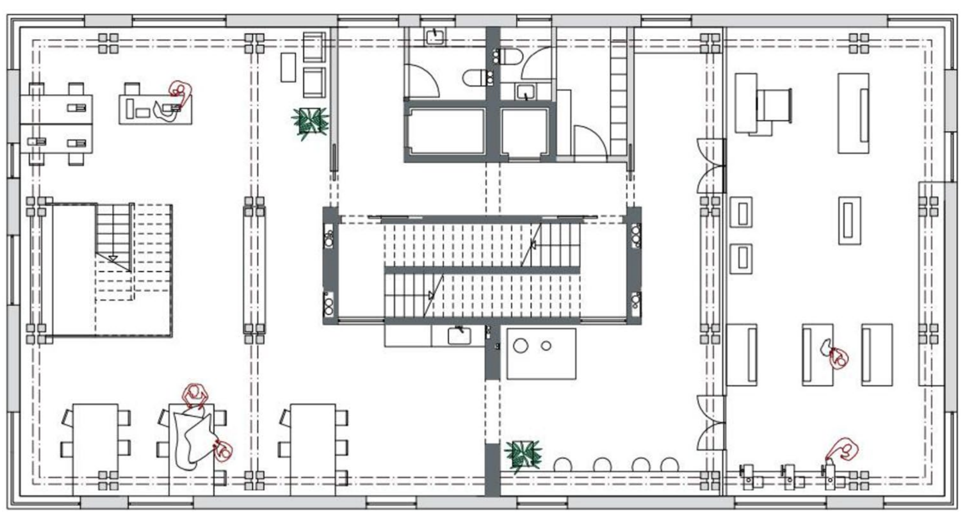

Fig. 38 Plan of the workshop on 2nd floor

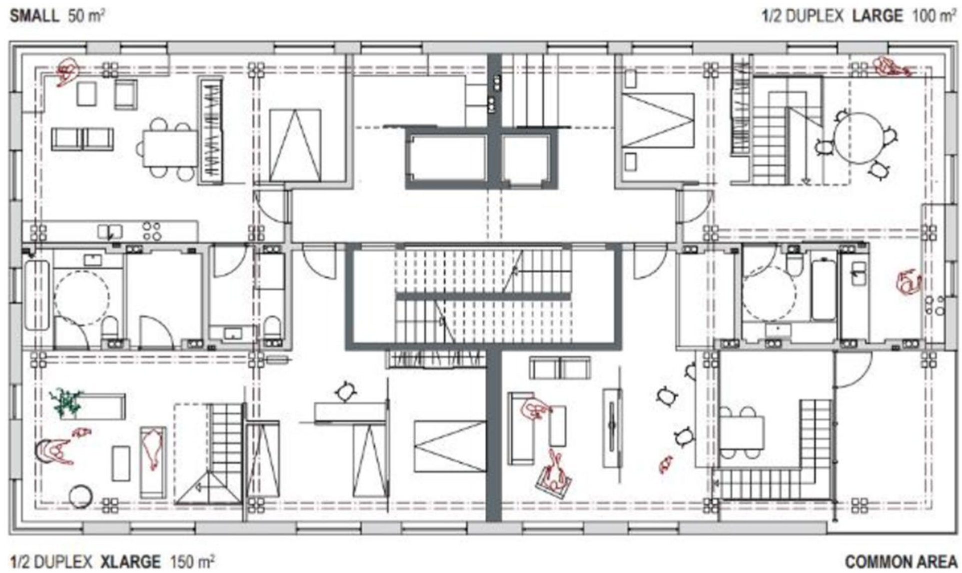

Fig. 40 Plan of the 7th floor with three different flats and an area for communal use

Fig. 41 Interior of a duplex apartment

of different-sized flats at each floor will also encourage a mix of dissimilar family structures and of people of different ages.

The skeletal structure in wood sets out the spaces and provides them with a character. The structure also prepares the ground for divergent functions despite side-stepping the temptation to establish larger spans. Dissimilar programs like a women's centre where many people are likely to gather, a workshop where materials are handled and transformed, and a selection of apartments of different sizes, are all accommodated by help of one, structural strategy.

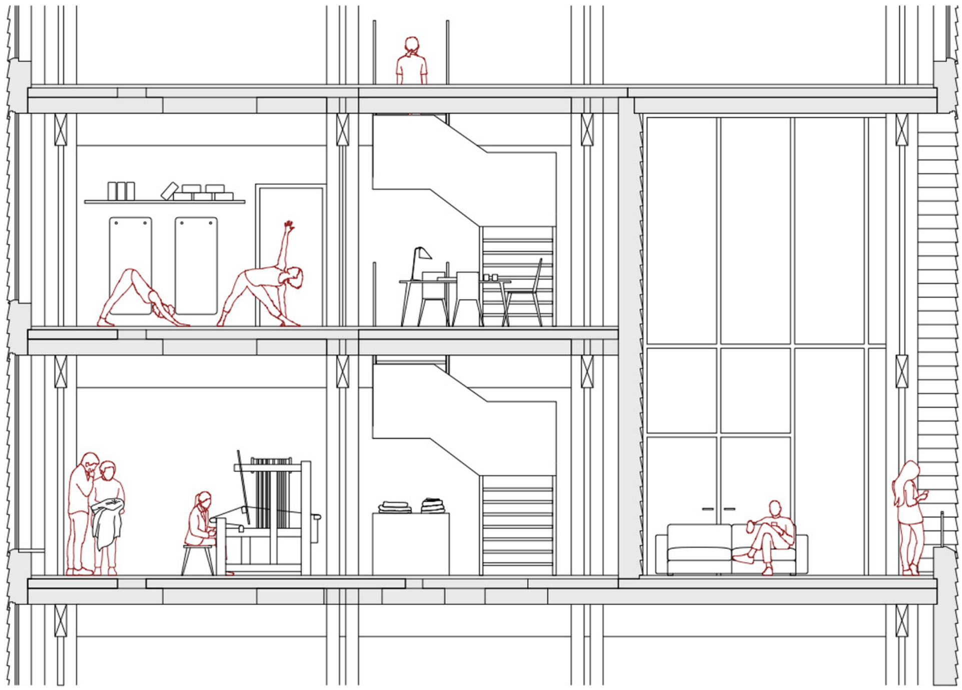

Fig. 42 Detailed section of mixed-use spaces, one of double-height

Some preliminary conclusions and further studies

This is not the end report of a finished investigation. At this point we are only able to make tentative observations from an ongoing process where we have set out to clarify whether for multistory buildings standard, hidden, non-descript, long-span structural systems represent a sensible way forward if beauty, appropriate flexibility of use, durability, and sustainability are seen as architectural aims. To help us with that we have students at The Oslo School of Architecture and Design, whose designs address these issues and many more.

We asked ourselves what might happen if structural systems were to be considered as true, architectural vehicles also for multistory buildings, a building category that perhaps constitute the most common of them all. Would the design of structures be able to release a creative energy that might advance certain architectural qualities? We think it fair to claim that this is really the case, but what exactly are those qualities? Studying the projects above, including the preliminary study models, it seems obvious that the variations in plan and section that we see; the intimate relationship that exists between the solid, the structure, and the void, the space; the way daylight interacts with permanent building elements; the possibility to see and touch materials of lasting presence; and above all, the intellectual and artistic gratification achieved by being able to perceive and understand what it physically takes to make the building, all these are seen as truly architectural qualities and would not have been present by any other means than by the structure.

What is more, it also seems reasonable to claim that pursuing a distinct, architecturally considered structural system of adequate uniqueness conceptually belonging to the architectural scheme, does not at all need to be a hindrance for future adoption of new programs. There is a versatility in the most common utility functions in architecture that enables these to live very well with structural interventions of many kinds.

To look at structures in terms of basic structural types seems to be a rewarding starting point for doing architectural design with ambitions for the structure. The various types present us with different ways of coping with loads, with different structural properties, and with different properties and qualities regarding use and visual experience of architectural spaces. We might consider these types as architectural ingredients: it is important to know how they work individually, but it is up to the designer (cook) to pick the right ones, to mix them, and to measure them out in proportions that produce a satisfying result.

Finally, how could one proceed with studies like this? What is clearly lacking so far are feasibility studies that go deeper into aspects like building process efficiency, construction technologies, and cost. Entrepreneurial expertise should be consulted. From this, one would bring in knowledge of a kind that also enables us to discuss more pragmatic issues, and to see this knowledge in relation to architectural ambitions for the projects. A discussion of *value* seems important, of *lasting* value. This notion should embrace more than short-term financial gain.

Declarations

Competing interests The authors have no competing interests to declare that are relevant to the content of this article.

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