VARIABILITY IN INDUSTRIALIZED BUILDING

Fundamental Questions of Variability in Design, Manufacture and Assembly

by

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Introduction

This short survey of a many years' research work introduces a condensed theory of variability in industrialized building, or better, it deals with the fundamental problems of application of variability in design, manufacture and assembly.

The theory has been founded on — and possibly proved by — the technological-experimental research work carried out at this Institute since 1971 ([1] through [10]) in the scope of silicate-based non-tectonic building methods.*

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About variability in general

The notion of variation in mathematics and in architecture

Variability, the striving after diversity — in general — is an inalienable quality of both the natural and the artificial world.

The *variation* — defined by *mathematics* in a characteristically *abstract* form as a definite set of a number k of elements sorted out from a number n of elements — in *architecture* always means a rearrangement of a *concrete*

* The silicate-based, non-tectonic building method is defined as a building method in which the final product (the building) is realized in a specific building process where additivity (that is, the axiomatic principle of building) is founded on the simultaneous non-loadbearing capacity and temporary instability of non-supporting (non-tectonic), semantically meaningless (Gutenberg-principled) surface elements. In this building method, therefore, the immediate object of manufacture is not the load-bearing structure but its surface, consequently, alignment of surface elements of vertical and horizontal structures does not lead to immediate load-supporting — load-transferring (tectonic) junctions between the surface elements. [6]

arrangement (e.g.: plan, structure, grouping etc.) from a definite point of view and in such a way that in the new arrangement the original thought, the *theme* remains recognizable.

Variability in traditional and industrialized building

In *traditional building*, more accurately: in the historical, *classical* traditional building, variability theoretically does not come up against obstacles, since this two-phased process of design — building is founded on the additivity of individually workable tectonic elements and so its variability is just boundless, as proven by the history of traditional building. This, however, does not apply to industrialized building.

In *industrialized building*, more accurately: in industrialized mass building, namely, the striving after variability may come up against very significant difficulties since this three-phased process of design — manufacture — assembly is based on the additivity of individually unworkable manufactured tectonic building components as proven by the everyday practice of contemporary industrialized mass building.

Coordination and variability

Coordination as an order of construction and an order of dimensions

This essential change of the nature of building, that is, this kind of raising building to a higher level of quality gives a decisive role to coordination in building industry. As opposed to mathematics abstracting the objects of reality and the interrelations between the objects characteristically in form of a "logical model", in architecture this indispensable abstraction appears in a geometrical form. In architecture, namely, the dimensions are not organized either in themselves, or in their relation to each other, but require some sort of construction.

In the industrialization of building it is, thus, *coordination* which calls into being the geometrical, constructional order, which, in the last analysis, equally permeates design, manufacture and assembly through organizing the interrelations, connections, references, etc. according to a certain order. Thus, coordination as such is a characteristic concomitant to all three phases of building.

The geometrical-constructional order established by coordination is — in itself — always universal and abstract, since theoretically it takes no notice of the quality of the structure, the material of the elements of a system, their junction, etc. and puts the emphasis on the *construction of dimensions* unorganized in themselves. In the practical application, however, this universal and abstract order appears in an individual and concrete form, since the actual order of dimensions cannot be pointed out unless the concrete application of a concrete system is already known, thus, the emphasis here is transferred to the *choice of sizes* for the already organized dimensions.

In industrialized building, the system of coordination is universal and so the object of reference is the whole of the building, since coordination is fundamentally nothing but a universally applied reference system extended over the whole of the building, that is, the process of design — manufacture — assembly.

The fundamental systems of coordination

The great fundamental systems of coordination that is: the systems of design (architecture), manufacture (structure) and building (assembly) establish a close contact with each other in every building method. Since, however, the elements, the parts which characteristically represent the building method and thereby directly influence the architectural efficiency from the point of view of variability show very different qualities depending on the *sizes* applied, therefore, speaking about variability, it seems most expedient to start from analysing the principles for the choice of sizes, or, more accurately: from the analysis of the requirements to be met by the sizes chosen.

Principles for the choice of sizes. Requirements

Modular sizes have to satisfy three fundamental requirements, such as:
— *additivity* (alignability of the elements), a quality of the elements or components of the system depending on their modular sizes and increments, on the bases of which one and the same element or various different elements fit into ("keep station" within) a given interval (distance) through repetition or combinative allocation.

It is evident that a single component of a modular size can only meet the grid of that size whereas the addition of components of several properly chosen modular sizes may give all modular dimensions. It is well known that the restriction of the ranges of sizes, that is, the significant reduction of the number of sizes of different components raises extremely sharp problems particularly if the assortment is small and the size of the component is big. Increasing the size of the component, namely, leads to decreasing flexibility. This phenomenon takes us to the second requirement:
— *flexibility* of the elements, a quality of the elements or components of the system depending on their modular sizes and increments on the basis of which one and the same element or several different elements may give the greatest

number of solutions within a given interval through repetition or combinative allocation.

It is evident that flexibility be kept within rational limits since if each individual modular dimension is to be respected within a given interval then the sizes of components cannot be selected, restricted, in other words: no simplification is possible. This takes us to the third requirement:
— *simplification* of the sizes of components ("preferential" dimensions), an operation of coordination of choosing from the possible range of sizes a rationally limited number of proper sizes which — due to their additivity and flexibility — may above all substitute for the unchosen sizes.

It is evident that simplification should also be kept within rational limits since an extreme reduction in the number of sizes would counteract essential requirements of additivity and flexibility and thus simplification too would become meaningless. And since the aim of simplification is exactly the dissolution of this contradiction, therefore a reasonable and efficient means cannot be other than to reduce the series of numbers (the total range of modular sizes) so as to be able to replace the missing (i.e.: unpreferred) numbers by combinations of chosen (i.e.: preferred) sizes to a maximum degree.

Combination, permutation and variation in building

In architecture it is actually the alignment of elements of different (coordinated) overall dimensions in different directions (according to a certain order, of course) which finally calls into being the arrangements with which the required lines, surfaces or spaces can be assembled, that is, realized on the additivity of the elements. In many cases there is quite a number of possible (generally repetitive) combinations of sizes available for creating the requested surface areas, spaces or groups of spaces and it is evidently practical to choose the most appropriate one (that is, the most favourable *combination* from design — manufacture — assembly points of view). In this case, therefore, different surface or space arrangements can be derived from the available combinations. These possible individual arrangements arising from combinations of elements of different sizes are called *permutations* (a term otherwise not in use in architecture). It is the combinative and permutative application of elements of different functions and situations which, finally, call into being in the final product, that is, the building, the *variations* which in the last analysis determine all the functional and architectural, structural and aesthetic qualities of the building.

Two domains of interpretation of variability

1. *Creation of spaces (additivity of the elements)*

In industrialized building, variability is known and interpretable in two domains.

The one is the *creation of spaces*. In this domain the basis of variability is the *additivity* of the elements since it is the three-way alignability of the elements which ensures the possibility for the architect to create various buildings from units manufactured for the same purpose.

2. *Redivisibility (flexibility) of spaces*

The other is the *redivision of spaces*. In this domain the basis of variability is the flexibility of spaces designed from the very beginning for redivisibility since in the last analysis this ensures the possibility for the user of the building to redivide, that is, to transform the existing spaces — with help of the architect — in one way or another.

. . . and the two methods for creating variations

From the above important conclusions can be drawn concerning the methods of variation. According to the two domains of interpretation of variability, namely, there are two possible ways of creating variations in industrialized building:

1. *additivity*

means to start out from some reasonably chosen plane — or space — unit(s) and add them up in different ways;

2. *divisibility*

means to start out from some given space and to divide it in different ways.

The four fields of application of variability and the four types of variations

The striving after diversity is not only an immanent, inalienable quality of architecture but a fundamental requirement as well. In our days this demand is particularly timely and justified by the fact that in industrialized building this endeavour runs counter significant technical obstacles and so it produces unfavourable effects in all fields where maintaining variability would be of explicit interest.

It is of interest first of all in *design* since "*planning for change*" and architecture are almost equal in age, but it is of the same important interest in *manufacture* and *building* since "*producing for change*" in our days has become so to speak a categorical social requirement and finally it is not indifferent to maintain variability in the field of *use* since as a consequence of the constantly changing social, economic, functional and technological requirements the demand on subsequent transformability of different spaces — consequently the claim to "*planning for transformations*" — grows multiplying.

From the above said, however, important conclusions can again be drawn concerning in this case the types of variations, that is, the quality of the variations created. The four fields of application of variability, namely, determine almost automatically the possible types of variations. In industrialized building, namely, the variations — depending on the field of application — can be divided into four fundamental groups of design, manufacture, building and use. Since, however, the object of variations in design is architecture; in manufacture it is the structure; in building it is the technology, that is, the method for realization; in use it is the new function, that is, the method for adaptation to new claims, therefore in the following we shall speak in due course about

design (architectural)
manufacture (structural)
building (technological) and
use (functional) variations.

The individual types of variations can be expediently determined as a function of the field of application, as follows:

1. *Variability in design*

In industrialized building, *variability of design* (architectural variability) is understood as a quality of the manufactured structural system, more accurately, a quality of the components of the system depending on the sizes and increments, which gives a possibility for the designing *architect* to create various final products, that is, *various buildings* from the components manufactured for the same purpose. In industrialized building, architectural variability is based on the additivity of these unworkable manufactured components, therefore the degree of the architectural variability of a system is best expressed by the number of the possible design (architectural) variations which, in turn, directly depend on the combinatorial qualities of the structural system. On this basis:

in industrialized building, *design (architectural) variations* are called all those possible building arrangements (variations on plan, in section, in layout etc.) which can be created by the architect-*designer* (in possession of a chosen structural system) in the final product, the buildings and their ensembles.

2. *Variability in manufacture*

In industrialized building, *variability of manufacture* (structural variability) is understood as a quality of the apparatuses manufacturing the units and components, a quality depending on the convertibility of the machine which gives a possibility for the *manufacturer* to apply standard machines for producing structural systems, more accurately: to mass produce units and components to be assembled in a structural system, which, *though technologically unified, can be different in sizes, increments, thicknesses, etc.* In industrialized building there are two possibilities of variability in manufacture. The one is based on the convertibility of the machines producing the units, the other is based on the additivity of the manufactured units. This is why the degree of manufacturing variability of a system is best expressed by the number of the possible manufacture (structural) variations and building (technological) variations (see below) from which it unambiguously follows that in industrialized building both architectural and technological variabilities are direct functions of the variability in manufacture.

In industrialized building *manufacturing (structural) variations* comprise all possible structural arrangements (variations on components, assembly of components, etc.) which can be created by the *manufacturer* (in possession of machines producing the chosen structural system and its components) in the system itself, in its components and subsystems.

3. *Variability in building*

In industrialized building, *variability of building* (technological variability) is defined as a quality of the manufactured structural system (more accurately: as a quality of the elements and components of the system) depending on their sizes, increments and finally, methods of assembly which — together with the auxiliary building, transporting, etc. systems that can be combined with the system — permits to construct the buildings in different ways (in other words: to construct from the units manufactured basically on the same technological principle but with different sizes, shapes, characteristics etc., the same building with different building methods). In industrialized building, variability of building is evidently direct function of the system's design and manufacture variability, therefore the degree of the building variability of a system is best expressed by the number of possible variations for realization which in final account means that the building (technological) variability will simultaneously be direct function of the manufactured structural system, the manufacturing apparatuses, the auxiliary building structures, the hoisting equipment and their combinatorial qualities. On this basis:

In industrialized building *technological variations* are understood as all possible building methods, realization variants which (in possession of the chosen structural system and of the apparatuses manufacturing the units and the auxiliary structures required for the transportation and site assembly of the elements) can be created by the *builder* in the very *building method*, that is, in the process of realization of the final product.

4. *Variability in use*

In industrialized building, *variability of use* (functional variability, architectural flexibility, subsequent flexibility in use) is defined as a quality of the manufactured structural system which renders it possible for the *user of the building* to transform the spaces, furniture, equipment without interfering with, and alteration of, the primary (load-bearing) structure. In industrialized building the degree of variability in use (degree of flexibility) is best expressed by the number of the possible variations for transformation which add to the value of use and are reasonably realizable in the interior (or, possibly, along the perimeter), which again is direct function of the combinatorial qualities of the structural system. According to this:

In industrialized building, *use (functional) variations* are all arrangements of subsequent transformations which (in possession of the built space and, of course, with an architect's collaboration) can be created by the *user* of the space in the very function and the degree of equippedness.

Correlations between the types and methods of variation

The *design* (architectural) and *building* (technological) variations can only be based on additivity since, in final account, the final product, the building, is created by additivity, by alignment of elements.

The *manufacture* (structural) variations, as far as the *elements* are concerned, can equally be based on *additivity* and *divisibility* since the convertibility of machines renders both ways possible; as regards the *system* composed of the elements it can only be based on *additivity* since the system arises through assembly of elements; finally the *use* (functional) variations are typically division variations since the new functions are made possible first of all by the redivision of the existing spaces.

The two constituents of variation

Just as in any field, also in industrialized building each variation — quite apart of its type — is composed of two groups of components, namely

1. the *constant* ones which maintain their characteristics (shape, size, position, function etc.) in each variation; and

2. the *variable* ones which — in a certain form and degree — change their features within the individual variations.

These components are present in each variation, they are clearly recognizable and their ensembles always represent the different ways of satisfying the same given function, whereas the different individual variations can always be distinguished by the types of the variable constituents and the degree of their change.

The "genus proximum" and the "differentia specifica" of the variations

Obviously, the selection of the type that is the "genus proximum" of variation practically decides the method of variation as well, whereas the factor by which the different variations belonging to the individual types can be distinguished, the "differentia specifica" of the individual variations is fundamentally determined by what of the constituents is considered as constant, what as variable and how the variable varies.

Principal factors of variability in industrialized building

Since in industrialized building the variations — whatever type they are — are in some way, directly or indirectly, connected with the components of the chosen structural system, variability in final account can only be enforced through the components, hence, from the point of view of variability, essential correlations exist between the geometrical, technical, technological features of the components and the types and methods of variation.

A very wide range of constituents has to be taken into account in each case. In each individual type of variation, however, from among the often conflicting items there emerges a fundamental constituent much overriding the others, a factor working as "primus motor", prime mover, which fundamentally influences, in fact, often determines all the rest.

Variability in design and the unit size

For the variability in design the unit sizes for the applied structural system are evidently of fundamental importance since — irrespective of whether they are tectonic or not — unit sizes have a fundamental influence on flexibility, decisive for architectural shaping. Thus, it is not quite irrelevant

- whether the structural system applies small units providing a high three-way flexibility, or
- medium size units are applied that can only be of parameter size in one direction of the space-grid, still leaving a considerable flexibility in the other two directions; or finally
- large-size plane or box units of parameter size in two or three directions, and so their flexibility is necessarily a minimum.

Namely, increasing the unit sizes unavoidably impairs the architectural efficiency of the structural system and this, in turn, runs counter the requirements of variability in architectural shaping.

Variability in manufacture and the convertibility of the machines

Variability in *manufacture* is evidently fundamentally affected — beyond the size — by the unit shape as well, by whether it is homogeneous or inhomogeneous, since the manufacture itself varies with these conditions. It is not irrelevant whether we produce small, medium or large-size elements of simple or of composite shapes, of homogeneous or inhomogeneous materials, in a plant or on the site whether they are to be connected in one, two or three directions. Even, since architectural variability ultimately results from the *convertibility of the manufacturing apparatus*, obviously the method of manufacture — by *conveyor, battery* or *caroussel-principled* production technologies — will rise to decisive importance since the machines can be made convertible in different ways in either of the three cases, in fact, the principle and method of manufacture will also affect the tools of transporting and hoisting systems both in the factory and on the building site.

Architectural variability, the alternatives of assembling structures in different planes and positions in space and in time, assemblability of units and jointability of structures

Variability in *building* is essentially affected by the alternatives of the assembly of units issuing from the method of building, that is to say, the schedule of building in space and in time from units of different sizes, shapes, in different planes and locations, also whether an *in-situ*, an *assembly* or a *box-unit* building method is applied.

In case of *in-situ* building methods, variability is excellent since the degree of complementarity is the lowest, the time schedule of building is unambiguously determined and the variability of the auxiliary structures is the highest. Assembly methods exhibit medium variability since the degree of complementarity is moderate, the time schedule of building has more variants, whereas the variability of the auxiliary structures is a function of these variants; finally, in case of the *box-unit* system, variability decreases to a minimum since the degree of complementarity is the highest, the time schedule is again unambiguously determined and there is practically no need of auxiliary structures on the building site.

Variability in use (variability in subsequent transformation) and the kind, number and spacing of supporting structures

Finally, for the sake of completeness we touch upon the question of variability in use albeit it is not a problem of building, but of subsequent reconstruction. As a matter of fact, its feasibility and range — provided the premise had been a priori pre-designed for this purpose — depends first on the *geometry of the supporting structures* (whether they are centric or linear in one or two directions) then on their *number*, and finally, on their spacing.

Summary

Variability, the striving after diversity is an inalienable quality of architecture. In the age of industrialized building, variability may come up against significant difficulties.

The study first analyses the basic correlations between coordination and variability, then determines the two domains of interpretation of variability in industrialized building, introduces the four fields of application of variability and the four types of variations, finally — after having stated the correlation between the types and methods of variation — gives a concise analysis of the leading factors of variability in industrialized building.

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