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BUILDING RESEARCH TRANSLATION

Account of the Principles of Modular Coordination: Industrialization in Building

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Account of the Principles of Modular Coordination: Industrialization in Building

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FOREWORD

The United States/French Cooperative Program on Building Technology entails an exchange of personnel between the National Bureau of Standards (Building Research Division) and the Centre Scientifique et Technique du Bâtiment (CSTB) of France. The program also involves the exchange of information between the two research organizations.

It is felt that some of the documented information can be usefully shared with the U.S. building industry; and, therefore, certain papers were selected for reproduction in media on sale to the public by the Government Printing Office. It should be understood that the CSTB documents made public through such media as this TECHNICAL NOTE do not necessarily represent the views of the National Bureau of Standards on either policy or technical levels.

At the same time, building researchers at the National Bureau of Standards consider it a public service to share with the U.S. building industry certain insights into French building technology.

James R. Wright

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ACCOUNT OF THE PRINCIPLES

OF MODULAR COORDINATION

Industrialization in Building

by

G. Blachère

This paper is translated from the French original and is published under the Building Research Division/ Centre Scientifique et Technique du Bâtiment information exchange program.

Modular co-ordination is indispensable to the industrialized production of units for assembly in buildings. It must be subject to the limitations which are strictly necessary to achieve this end. A large module must be chosen, the reference for the co-ordinating dimensions must be fixed, and the tolerance problem solved. This is the theme of the report.

Key words: Conventions; dimensional co-ordination; industrialized production; modular co-ordination; tolerance.

Necessary Conditions for Industrialization

1. Industrialization of the production of components and elements used in the erection of building structures presupposes a more extensive use of machinery, so that skilled labor is eliminated and all labor is reduced to a minimum. This means that depreciation will form a greater proportion of the total cost of the building, and that production runs will have to be greater to make the increased investment costs worthwhile and gain the maximum benefit from the reduction in labor.

2. Mass-produced articles may be thought of being incorporated into structures designed to be composed of preselected components. These structures may then be either proprietary model systems or "mail-order catalog" buildings on the "erector set" principle.

In both cases the components are manufactured with a view to being assembled together. Assembly entails that the dimensions of the components and the joint details be coordinated; however, these coordination conventions are unique to the firm or group of firms producing the model building or "erector set" parts.

This does not require an agreement between every designer of a building and every manufacturer. The construction of individual dwellings in the U.S.A. is a case in point: a large number of contractors use one and the same technique--loadbearing panels with a timber frame, placed side by side--and thus have an "erector set" system on a national scale.

3. A further possibility may be contemplated, however. Mass-produced units may be desired for use in any structure whatsoever. Such units could be used either for part of the structure (partially-open system of construction) or they may be used for the whole of the structure, which could then be an assembly of catalog elements bought from different manufacturers, (that is, a fully-open construction).

In either case (partially-or fully-opened construction), some convention is obviously necessary as to the shape, dimensions and quality of the elements, so that the designer can take into account what products are available on the market, and conversely so that the manufacturer can produce units which will fit into the architect's designs.

It is clear, therefore, that these conventions on quality, shape, and dimensions of open-system units should be accepted by all, whether designers of buildings or manufacturers who want to establish a market for the open system. A market of this sort could cover one region of a given country, or the whole country, or a group of countries, or indeed the whole world.

4. Conventions on quality may be expressed by means of an agrément or by a similar procedure.

5. The convention on shape appears principally at the moment as an agreement about jointing. In these partially open systems, in which the manufactured units are not directly assembled with one another but only with structures erected in situ and according to specification, no convention on shape is necessary; every manufacturer can specify how the "made in situ" parts are to be designed to fit the components he produces.

If, on the other hand, prefabricated components of different origins or playing different roles in the structure are to be fitted together, a general convention on jointing will be necessary.

Research towards establishing such a general convention is still in its early stages. Some remarks on this subject are appended to this note.

Dimensional Convention

6. It could be supposed that the dimensions to be given to the various components and structures are fixed arbitrarily, attention being paid only to the following: that there be no ambiguity as to the values of the dimensions given, the points between which they are to be measured, and the degree of accuracy they must meet; and the dimensions of the component and of the structure to be assembled be equal. For instance, it could be conventionally agreed that the distances between the axes of the trusses in a curtain-wall structure must be one of the following dimensions: 93, 147, 168, 252 cm, etc...and that the dimensions of the curtain-wall panels must be fixed accordingly.

Such a solution is possible in principle. But it clearly has fewer advantages than a choice of dimensions such that the sum of two accepted dimensions is itself an accepted dimension. Indeed it is current in building that a given structure must have one dimension equal to the sum of two others. For example, a floor-span equal to the sum of several widths of wall panels or vice-versa, one wall panel equal to the sum of several partitions, panels, etc.

In other words, the selection of accepted dimensions should have the property of additivity, that is the sum of two accepted dimensions is an accepted dimension.

7. If integers are being considered, only the product of integers possesses this property, together with the sizes deduced therefrom by multiplying every integer by the same factor. Any selection from among these loses this property.

If the common factor is termed a "module," it will be seen that in order to have the benefit of additivity, all dimensions which are the product of the module and any whole number must be accepted.

We shall see later how this module is to be selected. First, however, it should be emphasized that if additivity is to be preserved, there can be only one module in a given field of production and distribution of open-system components.

Choice of the Module

8. Since the coordinating dimensions are multiples of the module, the larger the module, the smaller the number of permitted dimensions within any given range.

A reduction in variety is often of great advantage to the manufacturer, but is always a limitation for the architect. The choice of the module results from a compromise between these two opposing standpoints.

The precise value of the module should, on the other hand, be chosen with due regard for industrial considerations. If it should happen that certain sizes are particularly common among semi-finished products, account should be taken of this fact. This is indeed the case: a width of one metre twenty (four feet) is very common for plates, fabrics, etc. It would, therefore, be advantageous to tie the module to this dimension of 1.20 m.

Furthermore, aesthetic considerations come into the question. Horizontal coordinating dimensions will often have to agree with dimensions for height of story and height of room, for which official minimum values exist in most countries.[§] It is important that the module or its multiples should harmonize pleasantly with these heights. This is one of the arguments which led to rejection of 1m for the horizontal module, since the dimension of 1m forms less harmonious rectangles with the heights of 2.50 and 2.70 m than those formed with the dimension of 1.2m.

9. The compromise between the architect's wishes and those of the manufacturers first led to the choice of the dimension of 10 cm for the module (this is the value now accepted by the I.S.O.).

The choice of such a small dimension for the module results also from the desire of some people to modulate every dimension, even the "technical dimensions" such as wall, column or floor thicknesses.

10. The idea of modulating technical dimensions has now been abandoned. The 10 cm dimension consequently seems too small, or rather the number of accepted dimensions which would result is too large to enable the fabrication of large one-piece components by means of a dimensional equipment assembly. This is the case put forth for injection molds and stamping dies. It would be too expensive to have sets of molds or dies dimensioned at 10 cm by 10.

[§]The most common dimensions seem to be 2.50 m room-height and 2.70 m story-height.

Larger modules have, therefore, been chosen, at least for horizontal dimensions: 30 cm for dwellings, 60 cm for industrial buildings. In the IMG glossary these are termed multimodules. In fact, they are just modules, large ones.

In some countries, the question has been raised of having larger modules, for example 3 or 6m. In practice, however, there are few manufacturers who would consider, independently of one another, supplying construction units for industrial buildings with dimensions which are a multiple of 3 or 6m. The truth of the matter is that in these cases, given a modular system by 60 cm, a construction grid of, say, 6 m would be chosen. On this basis, taken from all the possibilities offered by modular coordination, a small number of catalog structures or an "erector set" system has been developed.

11. Vertical dimensioning of components is independent of their horizontal dimensioning[§]

Different large modules may, therefore, be chosen for these two directions. No agreement has yet been reached on the vertical direction where 20 or 30 cm are proposed, at least not for housing structures and depending on the country. For industrial structures, 60 cm has been agreed upon for façade components. But, while large building components offer variable width and length, most of them are either of room height, i.e. the height from floor to ceiling, or of story height, i.e. the height from floor to floor. Hence the important thing is to limit the variety of room and story heights. This can be done without choosing between the vertical modules of 20, 30 or 60 cm: room and/or story heights are the vertical module indeed.

No significant limitation of room and story heights has so far been achieved. Heights of 230, 240, 250, 260, 270, 280, 290 and 300 are all currently accepted, 230 and 250 are accepted only for room heights and 270 only for story heights.

Restricting the variety of these dimensions is made difficult by the fact that these heights are laid down in official regulations which are difficult to get changed.

However, these heights do not correspond to either health or safety requirements. They result merely from a compromise between habit and economy.

[§]Except in the case of the dimensions of semi-finished products. A plate, for instance, may be used with its largest dimension made vertical or horizontal in two different components.

Expressing Modular Dimensions

12. Modular dimensions may be expressed in metric units. The units currently used in building are, depending on the country, the millimeter, the centimeter or the meter. Many users of modular coordination use the symbol M to designate the decimeter. Thus, a length of 230 cm would be written 23 M.

The problem remains as to what symbol should be used for large modules. Symbols such as M_3, 3_M, etc., have been proposed. We would recommend the form 3 M. The dimension 120 cm would then be written 4.3M. This mode of presentation is readily comprehensible even for those who are unfamiliar with the convention and no confusion is possible. This is not true of all the other formulas using indices or exponents, since the indices generally do not indicate a multiplicator but merely an order number. Thus M_3 would tend to be understood as a third-order module rather than three times the module, and exponents show the power M^3 would be read as M cubed.

Which Dimensions Should Be Modulated?

13. It is necessary to decide which dimensions should be determined according to the formula n x M.

It is obvious that not every dimension could be used to measure distance between any two points in a structure. It is quite possible to limit the use of modular dimensions to those dimensions which are essential for the possibility of assembling components to one another. These are known as "coordinating dimensions."

This coordinating dimension is measured on each of the components to be assembled or rather on the structure to be formed by the components already erected or the one to be erected. If the same manufactured product can be assembled or erected following different procedures, it is likely to have different coordinating dimensions for each mode of assembly. For instance, a concrete block which can either be laid dry or with a mortar joint will have two coordinating dimensions, a panel which could just as well be used either with built up rabbetes, or installed flush, has two coordinating dimensions (see diagram 21).

14. It is necessary that those dimensions which are coordinating ones in the structure under consideration should be modular; that is, those dimensions which determine the possibility of assembling components which are actually going to be connected in the structure being considered and not in all the possible assemblies in every structure. Thus in a façade which is inserted between the floors, the floor thickness is not a coordinating dimension for the façade since it does not affect the connections in the façade. On the contrary, it is a coordinating dimension for the height of the staircase.

However, it is possible to vary the incline of a prefabricated flight of stairs during its erection so that with a given flight of stairs, not one given height, but any height within a given range, may be met. Consequently, the thickness of floor is no longer a coordinating dimension and it becomes unnecessary to modulate it.

We have, therefore, two different reasons for not modulating a dimension. The first is that this dimension plays no part in assembly. The second is that a possibility of taking up may enable the use of non-modulated components.

15. These possible ways of avoiding modulating certain dimensions should be carefully looked for and used. They help to avoid having to give a dimension greater than absolutely essential merely for reasons of modulation, where the increase would entail higher consumption of materials and hence higher price without any concomitant improvement in value.

When the length of a slab is increased for modulation reasons, the dimensions of the room over this slab are increased simultaneously. The expense is greater, but so is the value for a greater useful area provided. But if such a slab only needs to be 14 cm thick, increasing this for modular reasons to 30 cm entails an increase in the volume of concrete required in the proportion of 7 to 10, and hence an increase in price without any added advantage to the future user. Increases in these "technical dimensions," are really inadmissible, and for this reason it is essential that there be a means of avoiding having to modulate them.

In order to avoid modulating technical dimensions, building systems should be chosen in which the width and height of a panel are coordinating dimensions but not its thickness; the length and breadth of a slab, but not its thickness; the height and length of an internal wall but not its thickness, the height of a column but not its thickness, etc.

If the plan of a construction is examined in this light with all the dimensions on it, it will become apparent that a plan includes a very great number of technical dimensions and some coordinating dimensions only.

This realistic view is the antithesis of the myth of integral modular coordination.

16. A further easiness has been found to make modular coordination more flexible: number-pairs system. It is known that if elements of length n.M and (n + 1) M are available, every modular length greater than n (n - 1) M can be achieved by adding these elements, and too, a great number of smaller dimensions.

For instance, with partition panels of 30 and 40 cm, a partition can be made of 30, 40, 60, 70, 80 cm, etc. This gives ease to the user and it is also very useful for the manufacturer.

The only limits to this device are that the system must operate with an increased number of joints and that the appearance of these numerous and irregularly spaced joints must be acceptable.

Attaching the Dimensions

17. Restricting the range of choice of dimensions is not enough to ensure that the aim of modular coordination is reached (to enable assembling components produced independently of one another.) For such assembly to be possible, there must be clear indications given as to how these coordinating dimensions, to which conventional values are ascribed, are to be attached.

18. Since the vital point is to enable assembly, where to attach the coordinating dimensions is clearly dependent upon the technique of assembly to be used. If we take a façade panel designed to form the façade of a building with an already specified structure, the coordinating dimension, i.e. the dimension affecting the assembly, will differ according to whether the façade is external to the loadbearing structure or consists of panels inserted into that structure.

In the former case, the panels will be bound to each other, and the dimension characterizing this mode of assembly, i.e. the coordinating dimension, will be the inter-axes span of the structure.

In the second case, where the façade panel is to be connected directly to parts of the loadbearing structure, the distance between faces of these structural elements is the coordinating dimension.

The coordinating dimension, whether it be inter-axes or between faces is hence defined on the existing structure. The component to be erected will be coordinated and called according to that structure (e.g. "panel to be inserted into a bay of p. 3M.")

It may be seen that the construction grid idea is not the basis for attaching the dimensions. The technical features have to be considered for each case and the dimensioning deduced from them. This will then lead to the drawing up of tables showing how the dimensions are attached to structures and components according to the different techniques.

19. If a new element is worked up which is not included in this table, the inventor may himself lay down how the coordinating dimensions are to be attached. This is until a universal convention is established to settle this matter, or until a number of manufacturers have started production of the new type of component.

It may happen that one and the same component may have several dimensions which are technically significant. A façade panel, for example, may simultaneously be inserted at its interior face and continuous at its external face. In this instance, obviously the designer of the panel will have had to make a choice between inter-axes and faces coordination. One or other of the dimensions has, therefore, been designed to provide take-up so that the other would then be the coordinating dimension.

If take-up is possible for both dimensions, the element has a dual use. This is advantageous from the manufacturer's point of view.

20. Similar considerations apply to the vertical direction. Sometimes room height is the governing factor for the assembly of a given component and sometimes it is story height. Then this height will be the coordinating dimension, thickness remaining a technical dimension.

It is futile to attempt to give one of these dimensions any pre-eminence over the other. No means of comparison is available presently which could decide such an issue. Inserted panels, loadbearing internal wall panels and partitions are bound to room height. Continuous external flights of stairs, service ducts are connected to story height.

This comparison has no great value, because no open-prefabrication yet exists and indeed it would be unwise to make a choice before acquiring experience.

21. The fact that dimensions may be attached differently (between axes or faces, for example, room heights or story heights) means that for some components there must be two sets of modular dimensions. (Only two sets will be needed so long as only inserted or continuous façades are considered; possibly more if other components in other technical systems are included.) Hence it has become necessary to have two floor dimensions, one for floors manufactured to bear on walls standing at distances between faces equal to P. 3M and another for floors bearing on walls at P. 3M differences between axes.

This complication is a minor one since it is a simple matter to change the production-length of a floor slab. This costs less than making all loadbearing walls 30 cm thick. On the other hand, it must not be thought that one coordinating dimension means only one type of floor. Floors bearing on walls at P. 3M between axes will vary according to whether these walls are 12 cm thick, or 20, or 30, especially in respect of the length given to protruding reinforcements.

22. The situation is rather different in the vertical direction. If the room height is to be modulated, the flights of stairs will not be, since their height is equal to the sum of the modular room height and of the floor thickness which is not modulated. Similarly, if the story height is modulated, then the partitions are not, and their dimensions will not be fixed.

This situation is not causing any difficulties at the moment. This is because a prefabricated flight of stairs can be erected with different angles of slope, so that a discrepancy of ± 3 cm can easily be taken up. However, a prefabricated partition has a take-up capacity of the same order to facilitate erection and to compensate for inaccuracy in the dimensioning of the loadbearing structure.

23. Some experiments have been made towards harmonizing the horizontal dimensions (between axes and faces) and the vertical dimensions (room and story heights).

One simple solution would be to limit the variety of wall and floor thicknesses by standardization. So far, the evidence does not show that the restriction thus imposed on technical dimensions has been balanced by any material advantage. It has further been suggested that sub-modules, i.e. fractions of the 10 cm module, should be used for this purpose. Again, the use of these fractions has not yet proved profitable in any way, especially since the dimensions of these sub-modules are practically the same as or even smaller than the tolerance values, which effectively precludes any advantage from the use of these sub-modules for dimensioning.

In fact, at the present stage of development of modular coordination considerations relating to the use of sub-modules seem to be academic exercises from the total lack of any practical experience.

Tolerances

24. When a builder himself constructs a house, a number of components designed and manufactured by him, the problem of productive accuracy of components, in other words the problem of permissible tolerances, is an internal one to the builder. However, when the contractor for a part of a structure comes to incorporate new components into an already existing structure, it is absolutely essential that he should know with what degree of accuracy the coordinating dimensions are appearing in the actual structure. There has been no discussion of tolerances until now because the dimensions under discussion have been theoretical. On the contrary, all actual manufacturing or constructional dimensions are indeed assigned tolerances.

25. Up to now, it has been usual for many prefabricated components to be assembled on/or into structural carcasses erected by traditional methods. Hence, the tolerances of the traditional loadbearing structures have to be communicated to the manufacturer. These tolerances are large. A commonly accepted value is ± 2 cm over a length of the order of magnitude of the dimensions of one room. We should prefer to say that the true outline of a bay is contained between two rectangles drawn one centimeter inside and one centimeter outside the precise design of the bay.[§]

[§]For a more general theory of tolerances, see "Note on the Problem of Tolerances in Building" (G. Blachère), Cahiers du C.S.T.B. no. 48, vol. 380.

To use the language of point deviation[§] this comes down to saying that the point deviation over a part of the structure of one room dimension is 1 cm.

It is possible to manufacture in advance components to be used in monumental type buildings (built on more careful lines), but this would entail a diminution in the potential market. Clearly, in some types of wholly-prefabricated construction, a much higher degree of accuracy than the point deviation value of 1 cm can be achieved.

Nevertheless it must be remembered that in large concrete-panel construction the point deviation actually recorded is not less than 1 cm.

It is, therefore, up to the manufacturer to decide whether he wishes to construct components to fit traditional structures or structures of similar accuracy (in which case, he will take into account the tolerance of 1 cm) or whether to choose to work only on more accurate structures.

This choice will have a vital influence on jointing techniques and on the provision made for taking-up.

It may be noted in passing that when components are manufactured for assembly with traditional structures, where ± 2 cm may need to be taken up over a given length, the fact "technical dimensions" are non-modular seems to be of little significance.

Convention on Jointing

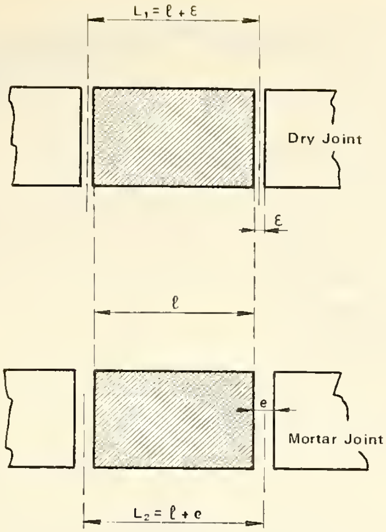
26. As noted earlier, if a prefabricated unit is to be assembled with a prefabricated or built-to-order component or structure, there is no need to refer to any generally accepted convention on jointing. In such a case the manufacturer will be told what configuration of joints he is to provide.

Of course, this does not apply when prefabricated catalog units from different sources have to be assembled together.

Very little progress has been made in establishing a general convention on jointing. There exists a convention whereby a component must stand within its modular space. Actually, it is merely a specialized form of a general convention on jointing, though it is commonly regarded as a major principle of coordination. It is a simple and effective convention, but an extremely limiting one from the technical point of view. In practice most prefabricated elements do not conform to this rule. There is, consequently, a need for a true general convention which will take into account actual jointing technology.

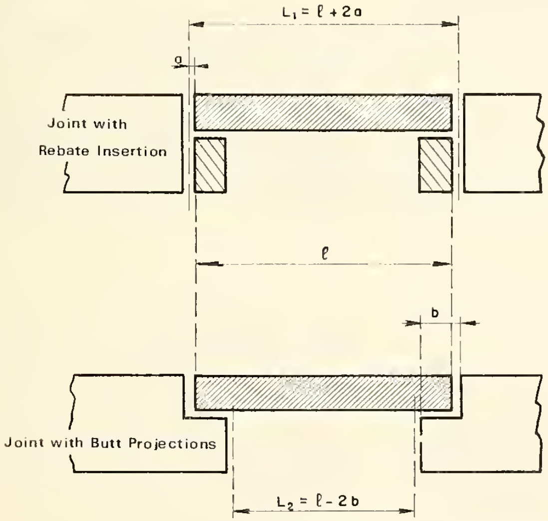
[§]Cf. French Standard NF P 01.101.

The establishment of a general convention on jointing remains, in our view, the most important task for us at present. This should provide builders, designers as well as manufacturers with an adequate set of conventions, enabling them to erect structures by assembling industrially prefabricated components selected from catalogs.



l = building dimensions
L_1 L_2 = coordinating dimensions

Figure 1



l = building dimensions
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Figure 2

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Modular coordination is indispensable to the industrialized production of units for assembly in buildings. It must be subject to the limitations which are strictly necessary to achieve this end. A large module must be chosen, the reference for the coordinating dimensions must be fixed, and the tolerance problem solved. This is the theme of the report.

17. KEY WORDS (Alphabetical order, separated by semicolons) Conventions; dimensional coordination; industrialized production; modular coordination; tolerance.

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