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SOME PRINCIPLES FOR DIMENSIONAL CO-ORDINATION AND STANDARDIZATION OF INDUSTRIALLY MADE BUILDING COMPONENTS

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Overall optimization: the goal for industrialization of building

1. The future development and use of industrially made building components depends on how far we succeed in striking a balance between the two conflicting objectives pursued by co-ordinating measures:

(a) To provide sufficient scope for flexibility in building design so that differences and changes in user requirements may be satisfied at negligible costs of dimensional and functional overdesign.

(b) To provide scope for large scale economies in component production and for labour-saving organization of component-assembly on site in such a way that overall economies of building may be obtained.

2. If we start by considering a very flexible system of dimensional, functional and other standardization there will be very small costs of the kind indicated by (a). As we introduce more and more simplifications and rigidities in our system the cost of the kind indicated by (a) will increase, but simultaneously we will obtain more and more economies (i.e. cost reductions) of the kind indicated by (b). Consequently we may identify at least one optimal point on the scale of simplifications, where the corresponding sum of (a) costs and (b) costs is minimum.

3. We may try to decompose the problem of overall optimization for the building industry by studying separately different building types corresponding to fairly homogeneous groups of users. It may then turn out that for some building types the optimal point of the scale of simplification corresponds to standardization of the end-product - the building - and a corresponding private "standardization" of specific components for a closed building system (the "model" approach) whereas for other building types considerations for increasing costs of type (a) may compel us to leave so much freedom in the design of buildings that the optimal point on the scale of simplification will correspond to an appropriate standardization of general applicable components (the "component" approach).

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4. The procedure described in paragraph 3 may lead to sub-optimization if we do not utilize the possibility of obtaining industry-wide economies of type (b) by establishing an integrated system of component standardization based on the idea of maximum use of identical or similar components for different building types, including those where standardization from a more narrow point of view might be based on the "model" approach. The discussion in this paper is, therefore, not restricted to housing, but concerns all building types, and the components which may be designed and produced for their assemblage on site.

5. Thus in order to define the future scope for optimal component development and production it is necessary to cross the "vertical" decomposition according to building types with a "horizontal" decomposition according to virtual component types, these being defined first by the interconnections necessary to make the building function properly when the components have been joined together, and next by the properties which these conditions impose on each group of similar components. This system work must be done centrally - preferable by government agencies in collaboration with the industry - and may probably be advanced to a considerable degree by being based on the logic and mathematics developed within the field of Systems Theory. After the central systems work has been carried out, design, development and production of components may be left to independent manufacturers of components, it being assumed that the conditions and properties which the whole system impose have been specified in sufficient detail to eliminate incompatibility problems.

6. The technical specifications mentioned in paragraph 5 include the rules for dimensional and functional standardization which to a certain extent are based on estimates of those economies of type (b), which may be obtained in the future, when new factories for new components have been established. These estimates will be based on inadequate information. As new technologies invade the building industry from other industries or are invented within the building industry itself it may be necessary to make radical corrections of the estimates, based on the new information on the "parameters" of the whole "system". It may e.g. happen that large scale introduction of computer control of processes in the building

/materials industries,

materials industries, introduction of numerical control of flexible machine tools for machining of component-parts and introduction of computer controlled assembly lines in the component industry may reduce the costs of flexibility in component production so much that new standards allowing more scope for variety may be optimal. What to standardize and how far to standardize will depend on technical and economic considerations.

7. This point may be further elaborated by taking into account the possibilities of utilizing systems of computer programmes for structural and other design of buildings. These programmes will be based on available components, but if the number of available components is e.g. tripled there will only be a once for all cost of adjusting the programmes and after that many designs may have better economy because a finer matching of components will be possible. Whether these economies will be off-set by diseconomies of component transportation and assembly on site depends on transportation systems, assembling techniques and control systems used on site for positioning of the correct component at the appropriate place. New systems may be so flexible that the extra cost associated with greater variety will be very small.

Technical co-ordination as an adaptive control process

8. The conclusion from the above considerations is that an optimal policy of technical co-ordination must proceed in stages. At each stage the system of technical specifications and standards necessary to ensure modularity in the general sense of optimal interaction between components must be based on a forward-looking evaluation of technologies. International comparative reviews of technologies would be helpful for such evaluations and particularly so for developing countries. After evaluation decisions must be made and specifications formulated. During the subsequent period new information will gradually make the system of specifications obsolete in the sense that it does not control the development process at an optimal level. The whole system of technical co-ordination must then be redesigned and adapted to the new or improved information now available. The purpose of such an adaptive multi-stage process of technical co-ordination is to secure that industrialization proceeds along an optimal path.

/The diseconomies

The diseconomies of overdesign [1/] associated with standardization of building components

9. A well known objection against the introduction of modular co-ordination and systems of preferred dimensions in building is that these restrictions on the sizes of available components will force the designer of buildings to design most rooms a little larger than required by the users. The validity of this objection depends of course upon the fineness with which intervals are spaced in the system of preferred dimensions considered, but assuming a reasonable spacing of intervals it may be argued that in very few cases will it be possible either for the users or their advisors to indicate exact user-motivated room-dimensions without simultaneously indicating correlated "tolerances" on these dimensions, which are so wide that they may easily be met by a reasonable system of preferred dimensions. The conclusion is that dimensional "overdesign" in the sense discussed above may be very insubstantial; the same applies to the associated diseconomies.

10. The term "functional standardization of components" is intended to indicate the result of basing component design on performance specifications for a broad range of applications in order to provide scope for large production runs. To ensure versatility in application components must be designed to meet the most unfavourable combination of performance requirements within the intended range of application and this again will imply "overdesign" for most applications. The objection against functional standardization is that the necessity of "overdesign" will involve diseconomies in most applications. In order to be valid this objection must assume either that tailor-made components could be obtained by industrial production at a lower cost or that it would be cheaper to construct components on site from parts processed for this purpose. In

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1/ The dangers of dimensional and functional overdesign have been discussed in the paper: "Influence of size, function and design on the standardization of components" by N.B. Hutcheson and S.R. Kent (published p. 210-211 in "Towards Industrialized Building. Contributions of the third CIB Congress, Copenhagen 1965" (Elsevier Publishing Company, Amsterdam-London-New York. 1966)).

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cases where one or both of these assumptions are true, and will remain true for a long time either standardization or complexity of factory-assembled components has been pushed too far, and we have identified a case of failure in striking the balance between the two conflicting objectives, (a) and (b), in paragraph 1.

11. Provided, however, that functional standardization, in the sense defined above, is kept within the limits dictated by overall considerations for building cost, there will be no diseconomies of overdesign.

The diseconomies of overdesign imposed on components by building codes

12. There is a danger that components will be unduly overdesigned for any specific application, if building codes enforce rules for structural and other functional design which ignore that qualities, dimensions and precision of sub-assembling may be kept within tolerance limits, which may be much closer in the case of industrially made components than in the case of components produced on site.

13. As a general rule it may be said that a reduction of tolerance limits for quality should be rewarded by permission to reduce specifications for average quality. This is a principle the consequences of which has not been discovered or implemented in many countries, and as long as this is the case, industrially made components are compelled to compete with conventional building on unfavourable terms.

14. Thus it may be concluded that the future design, development, use and cost of building components depend to some degree on how fast governments or their agencies proceed in introduction of scientific rules for structural design as well as for other aspects of design, which determine performance in use.

Flexibility in building design and its implications for component standardization

15. There is, perhaps, some ambiguity in the objective of flexibility in building design as expressed in (a), paragraph 1. Flexibility in design is required in the sense that the range of components should be sufficiently wide to allow designers freedom to arrange the plan, shape, internal climatic conditions, etc. of new buldings in congruity with the requirements of the user, which differ very much from one type of

/building to

building to another and even from one project to the next within the same type of building. This may be termed flexibility in the static sense. But flexibility is also required in the sense that most new buildings should be designed and constructed in such a way that they may easily be adapted to as yet unperceived changes in user requirements. This may be termed flexibility in the dynamic sense.

16. Flexibility in the static sense imposes the weak requirements that a wide range of sizes and functional capabilities of components should be available. If this requirement is adequately met, the diseconomies of dimensional overdesign will be negligible. Flexibility in the dynamic sense imposes the stronger requirement that components should be designed and assembled in such a way that a minimum of impediments are put against accomodating the building for related or new activities. Dynamic flexibility may be less important in housing than in other types of building. But for those types of building, where dynamic flexibility is necessary in order to secure long-term value of the buildings, we may provisionally conclude that components such as load-bearing room-sized boxes or structural systems based on densely spaced load-bearing cross-walls or columns may be inappropriate. It is possible to draw further negative as well as positive conclusions for component design and standardization by combining the requirements of static and dynamic flexibility, but we may stop by the reflection that as soon as flexibility in the dynamic sense is introduced explicitly as a criterion for standardization it appears that functional overdesign of components (in the sense of general applicability) is a virtue rather than the opposite.

17. Thus it may be concluded that the requirements imposed by dynamic flexibility may simplify dimensional standardization of components and may simultaneously rule out most of the worries about functional overdesign associated with standardization of components.

Co-ordination of component design by means of systems of preferred dimensions

18. The general principles elaborated in the preceding paragraphs may be used as a basis for establishing a system of preferred dimensions, which may be generally accepted by the building industry. A proposal for such

/a system

a system has recently been put forward in the Report: "Preferred Dimensions" by the Danish Ministry of Housing Development Group for Public Building (published in Danish with an English Summary as Report N° 56 by The Danish National Institute of Building Research (Copenhagen 1966)). The conclusions of the Report are indicated below, based on the English Summary of the Report.

Functional progamming

19. Studying a number of recent building projects mainly from two groups of public building (homes for the mentally deficient and high schools, which in various respects were found typical for public building) the development group found that relations between structural dimensions and functional programming (rather than detailed functional planning) should be analysed more closely.

20. Among other things functional programming is a choice of space standards (besides standards for installations, materials, equipment, and so forth). Complete freedom to choose space standards at random is for various reasons of no value in itself:

Functional requirements are changing with development, in some cases even during the comparatively short period between programming and construction of a building.

Functional programmes will almost invariably change radically during a building's lifetime.

Standard specifications for spaces derived from functional requirements cannot be very exact (even if they are often formulated so). Usually they are based on averages, and may be changed with development.

Often the same rooms or groups (rows) of rooms must be able to accomodate a number of quite different alternative functions (adaptability).

21. The conclusions from this analysis is that series of preferred dimensions should permit reasonable graduation of space standards. On the other hand differences between grades should be big enough to permit clearly motivated choice in each case.

A system of preferred dimensions

22. The problem of preferred dimensions has several times been approached in the past, and it seems to be generally and internationally agreed that:

(a) figures should all be multiples of a basic module;

(b) each larger figure should permit division by as many smaller figures as possible;

(c) between figures there should be such relations that larger figures are both multiples of the smaller ones - and sums of two or more of these;

(d) at the lower end of a series the distribution of figures should be more dense than higher up.

23. Evaluation of practical experience from industrialized building methods in Denmark during the last decade shows almost complete agreement with these rules.

24. The Danish development group has chosen a simple approach, which seems to meet all requirements. It is based on the fact that a series of figures with simpler relations than 1, 2, 4, 8, 16 (doubling) cannot be found. All figures have got equal relations to those smaller as well as to those bigger, and relations are arithmetic as well as geometric. Beginning with 30 cm (the planning module) accordingly the following dimensions may be considered a basic series:

30-60-120-240-480-960-1920-(cm)

25. Obviously, however, these figures alone are not sufficient. Differences are increasing to rapidly, and the question is how to cut them down systematically. The logical way is to cut into halves:

90-180-360-720-1440-.....(cm)

26. This series proves to be the same as the basic series above multiplied by the factor 3, and multiplying systematically the basic series by the factors 5-7-9-...each time still more differences are cut into halves (not all, but always the relatively biggest). This procedure can be continued until all multiples of 30 cm are included up to any choice of limit:

n = 1	3	5	7	9	11	13	15	..
30	90	150	210	270	330	390	450	...
60	180	300	420	540	660	780	900	...
120	360	600	840	1 080	1 320	1 560	1 800	...
240	720	1 200	1 680	2 160	...	...	...	...
480	1 440	2 400	...	...	...	...	...	...
960	...	...	...	...	...	...	...	...
1 920	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

Note: n is factor applied to basic series in the first column.

27. This arrangement of figures is characterized by the fact that relations between figures become gradually more complicated from left to right. Accordingly a decision on dimensional simplification may be made by dividing the scheme by a vertical line: all figures in the scheme left of such a line are then preferred dimensions.

Series of preferred dimensions for structural spans

28. The development group suggests that this system be applied in connection with a grouping of public building (eventually in connection with a grouping of private building as well). So far three groups are expected to be covering the needs:

Group A: (n = 1-3)	240	360				
	480	720				
	960	1 440				
	1 920	...				
	...	...				
Group B: (n = 1-3-5-7)	240	300	360	420		
	480	600	720	840		
	960	1 200	1 440	1 680		
	1 920	...	...	...		
	...	...	...	...		
Group C: (n = 1-3-5-7-9-11)	240	270	300	330	360	420
	480	540	600	660	720	840
	960	1 080	1 200	1 320	1 440	1 680
	1 920	...	...	...	...	...
	...	...	...	...	...	...

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29. The main part of public building in Denmark includes offices, institutions, schools and hospitals. Standards of quality as well as rules for functional planning being comparable, this part should refer to one group, viz. group B. Remaining parts of public building may refer to groups A and C respectively.

Preferred dimensions for smaller structural components

30. Various spans also need covering (filling) by rows or combinations of smaller structural components. Through an elimination process the development group has found the following preferred dimensions most suitable for this purpose:

30-60-90-120-180-240 (cm)

31. These preferred dimensions refer to all groups above. For each type of component depending on construction, materials, production, handling, and so forth, the most convenient dimensions are supposed to be chosen among the preferred dimensions above as singles, pairs, or groups.

Conditioning of heights

32. Official standards in Denmark are including the vertical planning module 20 cm and the floor-to-floor height 280 cm for multi-storey housing. As far as applicable the same standard dimensions should be used in public building as in housing.

33. A number of reasons have, however, convinced the Danish development group that 30 cm as vertical planning module may eventually be agreed upon internationally (and for housing, etc. 270 cm floor-to-floor height). As far as possible considering as well present as future standards the following heights are suggested:

	floor-to-floor height					
	280	300	320	330	360	420
roomheight	floor thickness					
250	30	50				
270		30	50	60		
300				30	60	
360						60

Still greater heights should be multiples of 60 or preferably 120 cm.