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Metric Dimensional Coordination— The Issues and Precedent

PROCEEDINGS OF JOINT CONFERENCE

WASHINGTON, D.C., JUNE 6, 1977

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Metric Dimensional Coordination— The Issues and Precedent

+ Special Publication

Proceedings of Joint Conference
Washington, D.C., June 6, 1977

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METRIC DIMENSIONAL COORDINATION -

THE ISSUES AND PRECEDENT

Proceedings of Joint Conference
Washington, D. C., June 6, 1977

Abstract: These edited proceedings are a summary of a Joint Conference of the Design Sector and Construction Products Sector of the Construction Industries Coordinating Committee of the American National Metric Council, which was held in Washington, D.C., on June 6, 1977. They may be used as a general reference document dealing with the background of and precedent in metric dimensional coordination.

As the United States prepares to join the metric building world, both the issues and relevant precedent in dimensional coordination become significant as a basis for an effective and economical change. To this end, the papers presented at the Joint Conference address the following topics:

1. Dimensional Coordination - An Industrial Management Tool, which reviews the issues and application of dimensional coordination;
2. Building Standards Development in Sweden and in the Metric Building World, which outlines issues in national and international standardization in the context of building design, production and construction dimensions; and,
3. Metrication - The Opportunity for an Industry-wide System of Dimensional Coordination: Precedents and Issues, which reviews precedent in metrication and the simultaneous change to preferred building dimensions and preferred sizes in component production.

The questions and answers emanating from the Joint Conference reflect the concerns of the United States' design and production communities at the outset of metrication and dimensional coordination.

Key Words: Dimensional coordination in building; International standards for building; Metrication; Preferred dimensions and sizes.

PREFACE

Since the Metric Conversion Act of 1975 was signed into law by former President Ford on December 23, 1975, industrial, commercial, and governmental groups in the Nation have begun to assess ways and means of accomplishing a successful and cost-effective transition to metric measurement.

In the construction industries it has been recognized that metrication brings with it the opportunity to transfer to a comprehensive and industry-wide system of dimensional coordination for buildings and building products. It is expected that the Design Sector and the Construction Products Sector of the American National Metric Council (ANMC) will be the main forces to bring about this transfer.

The Office of Building Standards and Codes Services, Center for Building Technology of the National Bureau of Standards, provides Secretariat and technical assistance to three sectors of the ANMC Construction Industries Coordinating Committee; namely, the Construction Codes and Standards Sector, the Design Sector, and the Construction Products Sector. In this vein, the Center for Building Technology cooperated with the Design Sector and the Construction Products Sector to arrange for this Joint Conference.

In the metric building world there is ample precedent of the benefits that can be achieved with coordinated dimensions for design, production and construction. One of the major benefits is greatly improved communication between all parties connected with building as an activity. At the international level, the concepts that underlie dimensional coordination are being set down in a series of international standards prepared by the International Organization for Standardization (ISO), Technical Committee (TC) 59, on Building Construction and especially by Subcommittee (SC) 1 on "Dimensional Coordination." TC59/SC 1 held its first meeting outside Europe in Toronto, Canada, from May 31 through June 2, 1977. Following this meeting, three participants, recognized as international experts in the field of metrication and dimensional coordination addressed this Joint Conference on June 6, 1977.

This document contains the proceedings of the Joint Conference, which was held at the Headquarters of the American Institute of Architects. It was prepared in response to requests by many of the attendees to make available the Conference technical papers and discussion on a much wider scale.

Special acknowledgment is given the American National Metric Council for cooperation in arranging for a joint meeting of two of its sector committees; the American Institute of Architects for making the facilities available; and, to the session chairman, speakers, and all Conference participants.

The special efforts of the following people are acknowledged for their contribution to the publication of these edited proceedings:

Mr. Rudy Dreyer	Chairman of the AIA Metrication/Dimensional Coordination Task Force, who taped the proceedings;
Ms. Sandra Berry	Building Standards and Codes Information Specialist in the Center for Building Technology, National Bureau of Standards, who transcribed, edited and coordinated these proceedings;
Mr. Hans J. Milton	Technical Consultant to the Center for Building Technology, National Bureau of Standards, who provided the technical assistance in editing these proceedings; and,
Ms. Sue Dzamba	Graphic Designer in the Center for Building Technology, National Bureau of Standards, who prepared illustrations from slides used at the Joint Conference.

James G. Gross
Chief, Office of Building Standards
and Codes Services
Center for Building Technology

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ABBREVIATIONS USED IN TEXT

ANSI	American National Standards Institute
BST	Building Standards Institute of Sweden [Byggstandardiseringen]
CEN	European Committee for Standardization [Comité European de Normalisation]
CIB	International Council for Building Research Studies and Documentation [Conseil International du Bâtiment]
(cm)	centimeter (10 millimeters)
CMEA	Council for Mutual Economic Assistance
COPANT	Comite Pan Americano de Normas Technicas
ECE	Economic Commission for Europe of the United Nations Economic and Social Council
EEC	European Economic Community of the European Common Market
EFTA	European Free Trade Association
EPA	European Productivity Agency
IMG	International Modular Group of CIB
INSTA	Inter-Nordic Standardization Committee [Internordisk Standardisering]
ISO	International Organization for Standardization
M	international basic module in building (100 mm)
MC	Modular Coordination
mm	millimeter
OECD	Organization for Economic Cooperation and Development of the United Nations
SAR	Foundation of Architects Research [Stichting Architekten Research]
SC	Subcommittee (in ISO)
SI	International System of Units [Système International d'Unités]
SIS	Swedish Standards Commission [Standardiseringskommissionen I Sverige]
TC	Technical Committee (in ISO)
WG	Working Group (in ISO)

WELCOMING REMARKS

GERALD PRANGE

Welcome to this joint conference of the Design Sector and the Construction Products Sector of the Construction Industries Coordinating Committee of the American National Metric Council.

We look forward to a lot of good discussion today under the guidance of two international authorities in the field of modular coordination and one world authority on metric conversion in the construction field. I know that Anna Halpin, Chairperson of the Design Sector, is very sorry that she cannot be with us today. She is a member of the American Institute of Architects' (AIA) Board of Directors and is attending a Board meeting out of the city. We are very pleased, however, to have with us today the Chairman of the Construction Industries Coordinating Committee (CICC), Mr. Clark Tufts.

Much of the motivation in the construction products and labor sectors of the building industry essentially is based on the view that metric conversion is coming--so let us soften the impact, if possible, by preplanning and problem solving.

The Design Sector appears to be more positive in its approach, with envisioned simplification of engineering design and standardization of architectural drawings and building components among other expected benefits. All groups, however--product manufacturers, building contractors, labor, and the design professions--are motivated to reanalyze the design and construction process, and to assess the extent to which modular or dimensional coordination presently is practiced in the United States.

Mr. Charles T. Mahaffey is the Senior Building Standards Specialist in the Center for Building Technology at the National Bureau of Standards. He is closely acquainted with our distinguished speakers and will make their introduction.

INTRODUCTION OF LENNART BERGVALL

CHARLES MAHAFFEY

Thank you. I cannot begin to tell you how much pleasure it gives me to introduce these three experts. I have been working with them now, on and off, for the past two years, and have found all of them to be extremely knowledgeable in their field.

The first man I would like to introduce is Mr. Lennart Bergvall. He is often looked upon as "Mr. Dimensional Coordination" in the metric building world. He has long been active in this field; in fact, he was a contemporary of our own Mr. Albert Bemis, who was generally credited as being the "Father" of modular coordination.

Mr. Bergvall was born in Sweden in 1912 and graduated as an architect from the University of Stockholm in 1934. He was Director of the Swedish Building Center from 1938 to 1941; and was the organizer and first Director of the Swedish Building Standards Institute. Since 1944, he has been a Vice Chairman of the Swedish Building Standards Institute and a Director of the Swedish Housing Research Corporation. He retired from his private Swedish manufacturing concern in March 1977. So, he has had a long experience in the design, manufacture and sale of products to the construction industry.

Mr. Bergvall is a member of the Swedish delegation to the United Nations' project on the international harmonization of building regulations. For 13 years, 1960 to 1973, Mr. Bergvall was Chairman of the International Modular Group (IMG), which is also Committee W.24 of the International Council for Building Research Studies and Documentation (CIB). This group is looked upon, particularly by the Technical Committee (TC) 59 - Building Construction, of the International Organization for Standardization (ISO) as the research arm in international modular activity. Mr. Bergvall has been Chairman of ISO TC59, Subcommittee 1 (Dimensional Coordination) since 1970, and was re-elected as Chairman of this Subcommittee at the meeting held last week in Toronto.

Please join me in welcoming Mr. Lennart Bergvall.

DIMENSIONAL COORDINATION - AN INDUSTRIAL MANAGEMENT TOOL

LENNART BERGVALL

INTRODUCTION

Let me take this opportunity to express what a great honor it is for me to be called upon to lecture on modular coordination in this very great country of yours, where the idea of a dimensionally-integrated house was born and for the first time clearly conceived. I am referring, of course, to the classical pioneering work of Albert F. Bemis.

It is encouraging, too, that your country is on the threshold of metrication. According to the Metric Conversion Act, I understand that the United States is going to be "a nation predominantly, although not exclusively, metric." This, of course, offers an excellent opportunity for dimensional coordination of the building industry, enabling you to "kill two birds with one stone." But, dimensional coordination is not a matter of "now or never," because sooner or later you have to go modular - if you do it "now" and take that unique opportunity, it is so much easier; if you do it later, it will be at a much, much higher cost.

Finally, let me apoligize if some of you will find my deliberation to be too elementary. But, I have been informed that some of you may not be too familiar with current concepts of modular coordination, which call for a "big picture" rather than detailed explanations. If necessary I will go into more detail during question time later on.

GENERAL REMARKS

I would like to point out that there is nothing mysterious at all about this modular coordination. As you will see, it is just plain common sense applied to the particular situation in the building industry. Over the years, there have been tendencies to turn modular coordination into some sort of mysterious philosophy of number series, etc. But, you will be better off if you forget about all this and take a solid, practical view of the obvious issues related to dimensional coordination in buildings.

HISTORICAL BACKGROUND OF MODULAR COORDINATION

A little historical background might clarify the situation. As a whole, modular coordination as a means of rationalization of the building industry is a comparatively recent innovation. While the use of modules as a means for the aesthetical coordination of the various dimensions of a building was already known and extensively applied in classical Greece and Rome, it was just prior to World War II that Albert Bemis outlined the basic idea of full dimensional coordination for the building industry. His concept was based on the use of components with dimensions being multiples of one basic unit: the 4-inch module. Before and during World War II, extensive work on modular coordination was also carried out in Germany by Professor Ernst Neufert, who was the first one in Europe to have a clear vision of the vital importance of modular coordination for the future industrialization of the building industry. But, he had a rather particular approach to it. He based his system of dimensional coordination on the "octameter" system, with a basic module of 125 mm, or one-eighth of a meter. For many years, this fact delayed full German participation in the international work on dimensional coordination. Other early studies of modular coordination were carried out in France by Jean Pierre Paquet; and France, it seems, was the first country to issue an 100 mm modular national standard.

In spite of all the battles that I have had with Professor Neufert, I must admit that it may be quite possible to base a system of modular coordination on 125 mm as well; however, the 100 mm basic module was the only dimension on which an international agreement could be reached.

During World War II, another study of modular coordination was carried out in Sweden by Dahlberg and myself. Our work reviewed the consequence, for the building industry as a whole, of full modular coordination based on a module of 100 mm, the nearest metric dimension to the 4-inch proposed by Bemis (4" = 101.6 mm). The investigation included service installations and equipment--which distinguished it from other studies of this kind; and, this is even more important now than when it was done because the relative cost and importance of installations in a building has grown enormously since those days. The confrontation of the American and Swedish work, which was made possible in 1946, when we met with the people engaged in the A62 project of the American National Standards Institute (ANSI), revealed that the independent work in the two countries had led to almost identical conclusions on most points.

After the war, the subject of modular coordination drew attention in several other countries, both in eastern and western Europe. In 1954, the European Productivity Agency (EPA) of the Organization for European Economic Cooperation (OEEC) began a study of modular coordination in which most western European countries took part. And, I am proud to be able to say that the ink of the signatures on the Rome Treaty on the European Common Market had hardly dried when we decided in the EPA group that, once the politicians removed the custom barriers, different forms of national modular coordination--at least--should not be a hindrance to international trade. When EPA closed down its activities in 1960, its work on modular coordination was carried on by a new study group, the "International Modular Group" (IMG), later to become a working commission of the Conseil International du Bâtiment (CIB). Thus, the basis for the international studies of modular coordination was widened since the members of IMG come from both eastern and western European countries, as well as from non-European countries. There is an astonishing degree of consensus, because a few countries started the work, and all the other countries have modeled their approaches on this precedent.

In 1959, modular coordination was also the subject of joint studies in the eastern European countries through the Council for Mutual Economic Aid (CMEA)--the Eastern European equivalent to the Common Market.

It was quite natural that the International Organization for Standardization (ISO) felt responsibility for the international development of modular coordination and, as far back as in 1949, a particular subcommittee, TC 59/SC 1, was set up to start international work on modular standards. Belgium was secretariat to this subcommittee. But, in reality, very little was done by that subcommittee during its first 15 years, and the real burden of the international work fell on IMG. Sweden now holds the secretariat of SC 1 and tries very hard to speed up work on modular coordination. The recent meeting in Toronto under the excellent hostship of our Canadian colleagues is an example of this.

At present, the work is divided between IMG, CIB, and ISO. It is recognized that all research work in the field should be carried out by IMG. It is the task of CIB as the sponsor of IMG and as an international research organization to create and provide new knowledge. Finally, ISO should transform the CIB results into international standards.

The gradually increasing recognition of modular coordination as an important tool for the rationalization of the building industry also led the United Nations Economic Commission for Europe (ECE) to be engaged in modular coordination. In 1959, an ad hoc meeting on the subject was held in Geneva and since then modular coordination has played an important part in all ECE seminars. The fourth ECE seminar, held in 1973 in London, had the theme "Harmonization of regulation and standards to promote international trade in building," and it strongly emphasized the importance of international work on modular coordination. The Policy Statement adopted by the seminar contains the following recommendation:

"A uniform and fully developed system of dimensional coordination in building should be adopted. It should include the establishment of uniform systems for the positioning of components and for joints, tolerances and fits in construction."

BASIC MODULE

Dimensional coordination is achieved by making the dimensions of all building and building components multiples of one basic dimensional unit - the basic module. This means that for full dimensional coordination, those dimensions of all building components which are of importance for its coordination with other components, and its coordinating dimensions, should be multiples of the basic module. However, only these general coordinating dimensions have to be modular. Thus, the external dimensions of a door set should be modular, because it is not known which wall components it will have to meet. On the other hand, the coordination of dimensions of the door frame and the door leaf can easily be carried out without being modular because the door leaf always meets just one known component, the door frame. Likewise, the dimensions of the building, i.e., the dimensions of rooms and openings, as well as thicknesses of walls, floors, etc., should be multiples of this basic module.

It is important to make the right choice for the basic module. It must be small enough to provide for the necessary flexibility in design of various buildings for various purposes, but also large enough to promote simplification of the number of sizes for various components. Finally, in order to ensure dimensional coordination at both the national and the international levels, the basic module must be internationally acceptable.

In Sweden in the 1940's, we conducted an experiment by preparing the drawings for a building project - as they were, as well as adjusting them to a module of 100, 125 and 150 mm, respectively. As for the unchanged drawings and those adjusted to 100 mm, 125 mm and 150 mm, the architects for the project were unable to determine which of them was their original design. This is confirmed by a British investigation which shows that the tolerance for proportions--to a normal human eye--is about 6%. It implies that those who want to make use of Le Corbusier's MODULAR or other proportioning systems can do so without sacrificing modular coordination, because the necessary adjustment to 100 mm modular dimensions would fall within that 6% limit.

As you all know, on these grounds we have had a unanimous international agreement on the basic module of 100 mm for a long time.

But, even this agreement was not easily arrived at. One of the problems occurred with Britain, where the possibility of a 3-inch modular system was seriously discussed. This is not surprising. The choice of 100 mm in the metric countries was partly based on the fact that many of the existing dimensions were already multiples of 100 mm, but no such obvious dominance of 4-inch dimensions over 3-inch dimensions seemed to exist in an inch country like Britain. As for the United States, the choice of a 4-inch module might have been influenced by the fact that nearly all your house construction is dimensionally derived from an almost universal wooden frame system, 16 inches between center lines.

And then, as I mentioned earlier, there was the German problem. One of the reasons for the German choice of 125 mm as a module was that it fit in so well with the existing German brick dimensions. Professor Neufert stated in one discussion: "When I started the work on modular coordination before World War II, I simply took as a basis what was already at hand in the brick dimensions." Maybe, it is not surprising that what "happened to be at hand" in the German brick industry in the thirties, did not form the natural dimensional basis for the building industry in the world of the sixties and seventies.

MULTIMODULES

It was recognized early on that the basic module is at times too small as a basis for standardization, because it would lead to too many variants. It seemed very natural to use instead, a whole multiple of the basic module as a kind of "higher" module, or what we now call a multimodule. There has been much discussion as to what extent multimodules are necessary. From the point of view of international cooperation, this was not the point - the important point was that the choice of multimodules was internationally agreed upon, and early enough to guide us all into the same coordinated dimensional pattern.

It would be quite disastrous if some countries pioneered values on their own. Then their industries would make large investments and later on it would be very difficult to coordinate, if at all. So, this is the reason that we must always try to be a little bit more advanced than the average.

The question as to what extent multimodules are necessary was finally solved by a more penetrating analysis of their raison d'etre. It was then agreed that the dimensional coordination of so called "additive components" could conveniently be carried out without multimodules, while for so called "single components" (e.g., prefabricated floor components), a multimodule would be a valuable tool for reduction of the number of variants. This is an important distinction in order to avoid an excessive use of multimodules which might imply a rigidity in design alien to the whole concept of modular coordination.

As for multimodules for horizontal dimensions, the now well-established series 3 M [300 mm], 6 M [600 mm], 12 M [1200 mm], etc., was finally agreed upon. But in the beginning, at the ECE ad hoc meeting in 1959, the series 2 M [200 mm], 4 M [400 mm], 8 M [800 mm], etc., also was seriously discussed and was supported by the USSR, while the other eastern European countries advocated the 3 M series. The reason that the latter eventually won was probably due to the considerable remaining influence of the foot system on existing dimensions, even in metric countries. For various reasons, the U.S. did not participate in these discussions; it would otherwise have been natural for it to strongly support the 2 M series, because of its coordination with the 4 M (16-inch) center line system for housing. As it turned out, the 3 M series was the only one for which general international agreement could be reached.

Multimodules for vertical dimensions were also discussed early on, and by 1961 a vertical multimodule was provisionally adopted within IMG. But soon, various doubts were raised about such anthropometrically determined dimensions as door heights, window sill heights, etc., being guided by a multimodule, and it was agreed that for such dimensions all the flexibility of the basic module was needed.

On this point there is still agreement. However, it was found later that for large vertical dimensions, e.g. story heights, etc., for which a 1 M flexibility would not be necessary, an agreement on a common vertical multimodule might be useful. This issue was discussed in considerable detail at the Toronto meeting, held May 30 - June 2, 1977.

SUBMODULES

For some parts of the building and for some building components, the basic module is too rigid; and for such purposes whole fractions of the basic module, sometimes referred to as submodules, $\frac{M}{n}$ are foreseen.

Much discussion has been devoted to the question of submodules, probably due in part to insufficient analysis of what purpose these submodules should serve. And, disagreement usually occurs when there is a lack of sufficient background analysis. Long experience in international work has shown that there is no such thing as one country being more clever or more knowledgable than another--but when there is disagreement it is usually because each is talking about the matter against its own national background, taking certain things for granted which are not evident to the others, or vice-versa.

It is sometimes supposed that submodules are needed particularly for the coordination of dimensions smaller than 1 M. A closer analysis of the matter, however, reveals that the relevant criteria can be found in the need for increments smaller than 1 M [100 mm] (e.g., for components in service installations, or for the standardization of wall or floor thicknesses). Prefabricated service installations are likely to make extensive use of submodules. I can assure you of this based on my background of having started and operated a system of prefabricated houses, which was used to erect thousands of houses fully modular in all respects, including all the installations.

But, all the time, the basic 100 mm module must be respected as the smallest permissible planning module for the building.

MODULAR GRIDS

To ensure that the building is designed to fit standardized modular components, the architect may design it on a modular planning grid. The basic planning grid, thus, is a basic modular grid, having a meshwidth (spacing of grid lines) equal to the basic module. When multimodular components are used, the building, or that part of it which is influenced by these components, may be designed on a multimodular grid.

From the very beginning of modular coordination, modular grids have been given considerable attention as a means of facilitating the design of modular buildings in which all modular components would be easily applicable and fit together. But, the degree to which they have been used has varied from country to country. The IMG "Condensed Principles of Modular Coordination" concludes that the modular grid "being a tool for the designers may, or may not appear on the drawings."

In most countries where the use of modular grids is considered important, the grid is normally applied in such a way that lines in the multimodular grid coincide with center lines, for example, load-bearing walls. The very early modular recommendations (Bemis, Bergvall and Dahlberg) foresaw a basic modular grid, in which the lines coincided nominally with the surfaces of walls, floors, etc.

When the multimodules were introduced, some people were so impressed by the great reduction of variants that could be achieved with them, that the 1 M [100 mm] flexibility of the basic module was almost abandoned. That was when Europe was drenched in an avalanche of concrete panel systems, where only the load-bearing structure counted. But, gradually there has come a dawning realization that, with the modern requirement of flexibility and growing importance of service installations and equipment, the basic module of 1 M [100 mm] flexibility must be retained internally, though not necessarily for the load-bearing structure or the external envelope.

The Dutch SAR system--originally created by Professor Habraken of the Massachusetts Institute of Technology (MIT)--foresees, instead of a 3 M center line grid, a sort of "tartan pattern" of 1 M [100 mm] and 2 M [200 mm] gridline distances, by reference to which all components are positioned. The system, which derives from some interesting concepts of modern building, could possibly be used as a tool for the reconciliation of the basic modular and the multimodular schools of thought.

It is very important that modular coordination is not interpreted in such a way that it imposes the rigidity of multimodules on everything in the building, as there has been some tendency; but, I think, that there has been a dawning realization now of the need to retain a 1 M flexibility, particularly in residential work.

TOLERANCES

The rules for dimensional coordination, described briefly, should ensure that the dimensions of various components do "nominally" fit to each other and to the building. No component can ever be manufactured or assembled with absolute precision, particularly in the building industry; therefore, dimensional deviations must be foreseen. To ensure that components also fit together in reality on the building site, a system of tolerances has been worked out for manufacture as well as for assembly, based on the experience in this field gained in other branches of industry.

It should be noted, however, that modular coordination calls for "determined" and "known" tolerances. Modular coordination does not call for narrow tolerances; that is entirely a matter of design.

MODULAR COORDINATION AND THE BUILDING INDUSTRY

My practical experience derives from the production of prefabricated houses, on one hand, but also from taking part in the development of the largest group of building materials companies that exist in Sweden. In a way, I prefer to talk about "dimensional coordination" rather than modular coordination. Dimensional coordination is what we are aiming at, and it is only because the module is the appropriate tool for this dimensional coordination that we are talking about "modular coordination."

Dimensional coordination, as a concomitant of standardization, normally is considered to be primarily an industrial tool, but I think that it is just as much an architectural tool, and that is important. It is not just a coincidence that all the early pioneers of modular coordination have been architects: Bemis in America, Paquet in France, Neufert in Germany, etc. We simply saw the inevitable approach of industrialization of the building trades with its equally inevitable complement, standardization. The question was not and is not, on this threshold to a real industrialization, whether or not we want it, but how we can be its masters and not its slaves. How will we be able to retain all the considerable and important gains of industrialization - important to all in need of better and cheaper dwellings - without sacrificing that deeply human and cultural aspects of building that is architecture. Thus, modular coordination is one of the tools so desperately needed in our age to make industrialization human.

INDUSTRIALIZATION

A close link remains between dimensional coordination and industrialization. I am aware, of course, of the fact that this term "industrialization" is a rather loose one and many more or less sophisticated attempts have been made to give it a strict definition upon which I shall now embark.

Even if we disregard the more terminological refinements, there are a number of features in this process which deserve our attention:

First: There are many degrees of industrialization and, to a large extent, the building industry as a whole is only in the initial stage of industrialization that appropriately could be described as "paleo-industrialization."

Second: The entire building community is in a period of swift change with many profound effects on the building industry as a whole, and not least on the building materials and component industry. One of the most important changes is the irresistible trend toward integration. As an example, around 1900 the structure of a building represented about 85% of the total cost, while equipment and service installations were about 15%. Current figures are rather like 40% and 60%, respectively.

Third: The trend towards prefabrication - in a broad sense - is equally irresistible in spite of some incidental setbacks. It will have the result that many of the products now produced by the "building industry proper," (i.e., on the building site) will be taken over by the material and component industry and produced in factories.

If we look at the building industry in this light, it will enable us to see much more clearly where and why standardization and modular coordination enter the picture.

DEGREE OF STANDARDIZATION

Repetition of operations often has been referred to as a means of "effectivization" of the building industry. But, it is only the very first step in an industrial evolution, which generally proceeds in the following steps:

- repeated operations
- long runs
- continuous production
- mass production
- automation

These steps have some overlap, of course, and, as a whole, this classification does not pretend to be a very sophisticated one. However, it describes fairly well to what extent we are beginners in the building industry compared with several other industries. We are now striving at the stage of "repeated operations" and, in the most advanced cases, at the stage of "long runs." Sung in that light, you may not find the phrase "paleo-industrialization" to be too much of an overstatement.

To enable the building industry to proceed to more advanced stages of industrialization the next step to be taken is from "production to order for specific projects" to "production for stock for anonymous projects." This also is probably the only way for the building industry to overcome the very disturbing seasonal variations in demand. But, for such a continuous production for stock, an effective standardization, based on modular coordination, is an absolute prerequisite.

INTEGRATION

One of the most important trends in the building industry of today--the integration of all production activities involved in construction--will interfere very deeply with existing practices and patterns. It also will call for a much closer cooperation between the different experts and specialists involved. This will affect particularly the design and development of products. No longer will a material or component manufacturer be able to afford to develop his product by considering only his own production conditions or the manufacture of only his particular product at the least possible cost. The problem no longer is to minimize the cost of any product, even as installed in the building, but it is an optimization problem of designing and developing every product with regard to minimization of the total building cost. Those products which subordinate themselves to this common purpose will be the ones to survive in this age of swift changes. This is another point where modular coordination comes in, because its purpose is precisely to provide a tool for the dimensioning of building materials and components, with due regard to their interplay with other components, as well as the building as a whole.

PREFABRICATION

Prefabrication is perhaps the most obvious and striking feature of the transformation process we are now witnessing in the building industry. For the building materials and component industry this means that it can, and must, gradually take over more and more from the building industry on the site. This also means that all these new so called "prefab" products must be applicable to a great number of very different buildings, even if some components may be intended mainly for housing, others for schools, etc. For this flexibility in application, modular coordination again comes into the picture as an indispensable tool.

This analysis shows us what a key factor modular coordination could be for the industrialization of the building industry and its concomitant, standardization.

STANDARDIZATION NOW AND IN THE FUTURE

We must recognize that standardization by its nature always means an optimum compromise between the designer's--or user's--natural inclination towards a rich assortment from which to choose, and the manufacturer's equally natural inclination towards a limited number of variants and the ultimate dream of just one single variant. Until now, this is how standardization has always been approached. But in a longer perspective, beyond the horizon of automation and computerization, we can envision a rather different, much richer and generous choice of variants within the framework of the production program; we will reject instead all kinds of "specials" due to their prohibitive costs. That will be very different from the situation of today, where many manufacturers--with or without their knowledge--are letting the 90% standard production heavily subsidize the 10% specials.

When we arrive at that highly-developed production technique, modular coordination will again provide, an excellent tool for the dimensional programming of such a computerized production process. However, such a highly-developed building industry, far beyond the "paleo-industrialization" of today, cannot exist within the narrow, national borders of any one country, at least not within the borders of any one small country. And this is what establishes such a close link between modular coordination and internationalization of the building industry.

CONVERSION TO MODULAR COORDINATION

Finally, I want to say a few words about the problems of conversion to modular dimensions and the implementation of modular coordination.

Normally, I point out that the problems of conversion to modular dimensions should be approached with the fact in mind that no existing industrial equipment or tools will last forever. On the contrary, in this age of swift changes, a good deal of equipment might be turned obsolete by development and need to be replaced long before it is technically worn out. This tendency normally will facilitate greatly the conversion to modular dimensions. But, in your particular case, you have the unique opportunity to combine the conversion to modular coordination with the conversion to the metric system. That situation is a different one, and I think, your British, Canadian, and Australian colleagues would be much better advisers to you than the Swedes.

In general, it is necessary in the successful implementation of modular coordination that one single national body, with sufficient authority and confidence, be responsible for carrying out the conversion to coordinated, modular dimensions.

Furthermore, the work of such a national body should be based on a thorough national investigation of dimensional coordination to establish the consequences of, and suitable methods for, a conversion of the building industry to coordinated modular and metric dimensions. Such an investigation must consider the influence of modular coordination on design, as well as on production of components. Also it should consider work on the building site. For instance, it will be necessary to establish which building components are of the most basic strategic importance and thus function as "key components" for the conversion. This is important.

It will be so much easier to carry out metric conversion and implement modular coordination if you start with the key components.

Other important activities in the conversion work will be the tasks of information, education and re-education on all levels in the building industry; from management and professors down to apprentices and students. The aim of the education program should be, that in future, modular coordination shall be considered by everyone to be the natural and simple thing it really is.

Much more could be said about this problem of implementation, but that would call for you to endure still another lecture.

CONCLUDING REMARKS

I hope that this very condensed account of dimensional coordination has given you some idea of what it is all about. When you consider for how many years modular coordination has been discussed and studied, you may well ask why we have not solved all these problems long ago, so that all the solutions are available. As a matter of fact, the development of modular coordination has been a slow and tedious process, demanding patience. This is quite natural. Changes that require existing, well-established patterns to be abandoned are always slow and difficult to bring about.

Furthermore, dimensional coordination can yield its harvest only as a joint, collective enterprise. As a whole, no one will gain individually by going modular all on his own, but everyone will gain by everyone going modular.

There is the usual desire to have the cake and to eat it at the same time. It is often expected that modular coordination will offer full dimensional coordination and yet leave everything unchanged or free - at least, one's own product or practice. Modular coordination also is expected to be internationally coordinated and yet leave all national habits, practices - and codes - unchanged. We, who have advocated modular coordination for some time; have never pretended that such a thing ever existed.

Finally, this prompts me to draw your attention to a difficulty, which, I believe, is a special U.S. problem--the non-unified local building codes. It could well be that the conversion to metric will give you an opportunity to solve that problem on which I think I shall not dwell. But there is a close link between modular coordination, nationwide standardization, and the need for more unified codes all over the country.

In the beginning, I referred to Professor Neufert's work on modular coordination in Europe. As a matter of fact, it was he who opened my eyes to the importance of dimensional coordination during a lecture in Stockholm, Sweden back in 1942. After having listened to his lecture, I felt ashamed to belong to an industry whose task it is to put together on the building site things produced elsewhere, but which had not undertaken a systematic dimensional coordination at least 50 years ago. Unfortunately, now and then, I still have to feel ashamed. I hope you, too, will feel a little bit ashamed.

Let me conclude by wishing you every success in your important work on metrication. I think it will require all that boldness in approach that we usually consider to be typically and truly American.

INTRODUCTION OF HENNING ORLANDO

CHARLES MAHAFFEY

Our next speaker, Mr. Henning Orlando, is a man who is quite familiar with the whole building standards picture. He is the Managing Director of the Building Standards Institute in Sweden. Mr. Orlando is a distinguished member of the American Cryptogram Association, and his hobby is developing secret communication codes. He is considered to be one of the top twenty experts in the world in this particular subject area. That gives you some idea of Mr. Orlando's quick wit and his ability to grasp large problem areas and reduce them to the essence.

Henning Orlando was born in France in 1914. After graduating as an architect from the University of Stockholm in 1940, he was engaged in the practice of architecture for almost 25 years. In 1967, he became Managing Director of the Swedish Building Standards Institute.

Mr. Orlando has been a member of the advisory council of the Swedish National Board of Building and Urban Planning since 1969, and a member of the International Modular Group since 1968. Also, Mr. Orlando is Chairman of Subcommittee 11 (which deals with kitchen equipment) of ISO Technical Committee (TC) 59. Henning also is Chairman of ISO TC59, Subcommittee 6, Working Group 4, which is attempting to develop international standards for stairs and staircases; he is the Chairman of ISO Technical Committee 10, Subcommittee 8, whose responsibility it is to develop international standards for the building drawing practices. The Swedish Building Standards Institute holds the Secretariat for a surprisingly large number of ISO technical committees and subcommittees, and Mr. Orlando will touch on that in his talk.

Mr. Orlando will give us a picture of building standardization in Sweden and of how dimensional coordination fits into that particular subject area. Will you join me in welcoming Mr. Henning Orlando.

BUILDING STANDARDS DEVELOPMENT IN SWEDEN AND IN THE METRIC BUILDING WORLD

HENNING ORLANDO

INTRODUCTION

Lennart Bergvall told you that he was very honored to be here with you. I am also very honored, because this is my first visit to the United States. It is a great pleasure for me to be in your very great and famous country.

While my fried Lennart has taken you up into the higher spheres of modular coordination, I will try to get you down to the ground again and show you which are the practical problems we are working with today.

STANDARDIZATION

Standardization has been defined by the International Organization for Standardization (ISO) as follows:

> "The process of formulating and applying rules for an orderly approach to a specific activity, for a benefit, and with the cooperation of all concerned and, in particular, for the promotion of optimum order and economy, taking due account of functional conditions and safety requirements, based on consolidated results of science, technology and experience, determining not only a basis for the present but also for future development."

Well, that says quite a lot, but how does it really work in practice? After standardizing in building for about 35 years in Sweden, we still are asking ourselves: "What is standardization? Are we on the right track? How can we do better? What is going to be done next?"

Perhaps, standardization means avoiding a situation such as shown in Figure 1.

Or, perhaps to get things around the human model more coordinated, as demonstrated in Figure 2.

It is surely not a question of trying to get the results indicated in Figure 3.

For hundreds and thousands of years, the human body has been the outline for all measuring, and you are likely to recognize this famous drawing by Leonardo da Vinci, reproduced in Figure 4.

Even before da Vinci, the human body was a start for standardization and coordination. Once, in a country somewhere, the people asked their king to give a footprint. This footprint was then used as a standardized size.

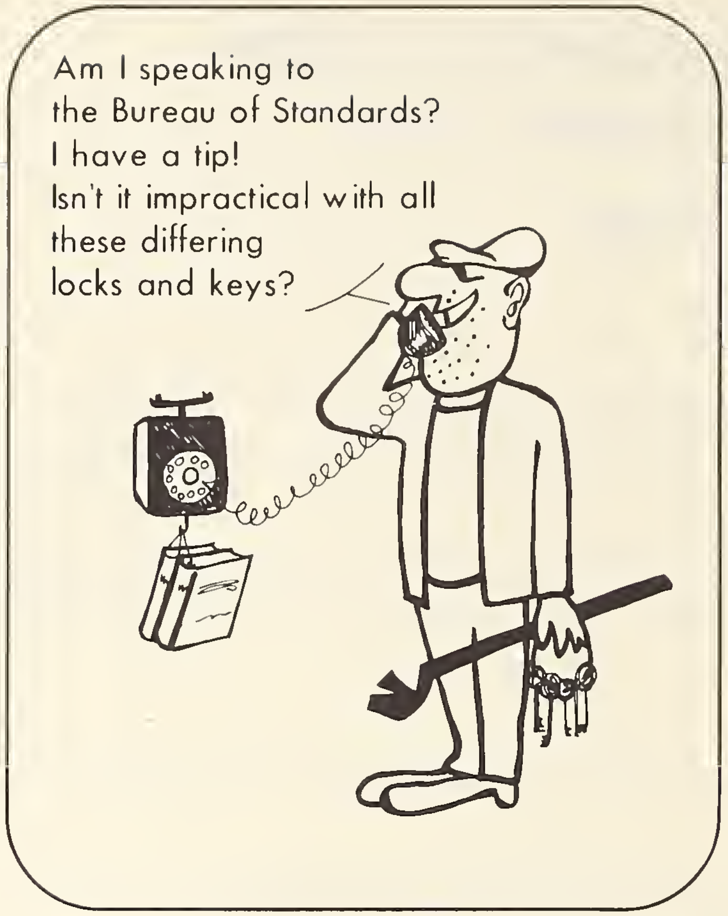

Figure 1

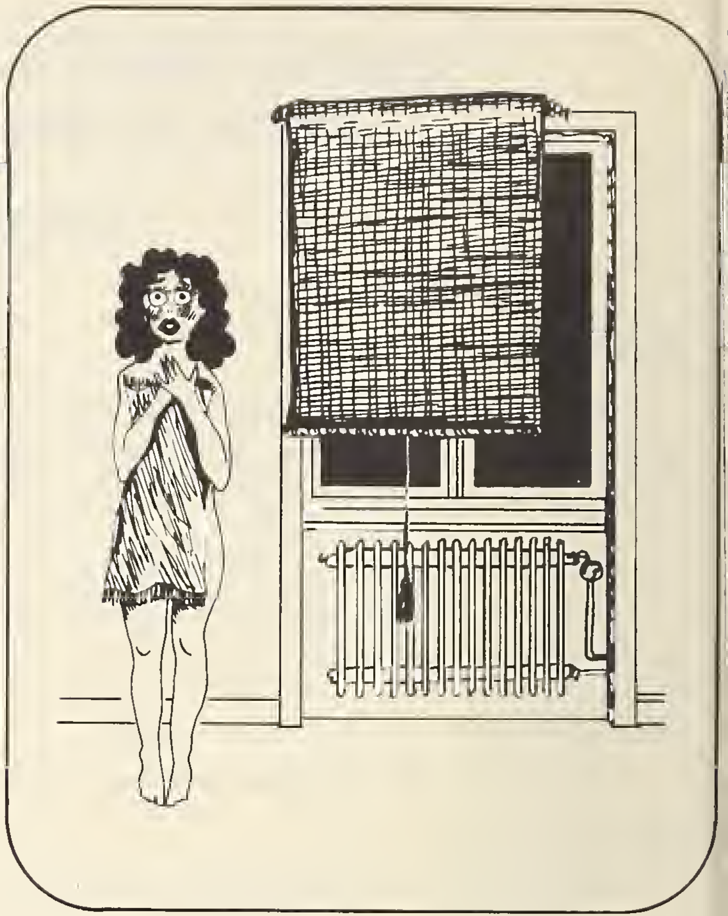

Figure 2

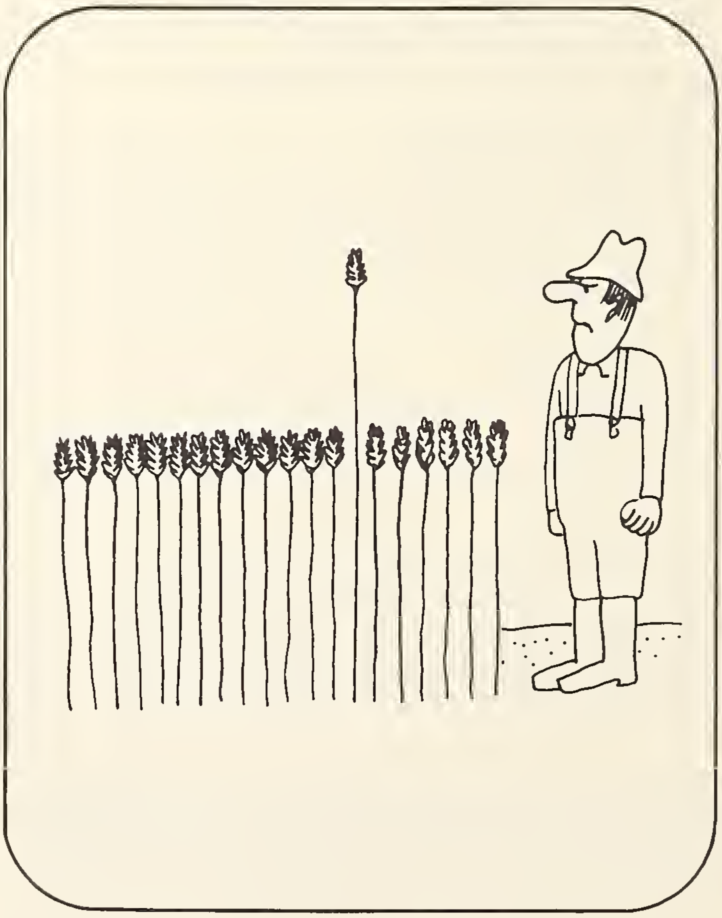

Figure 3

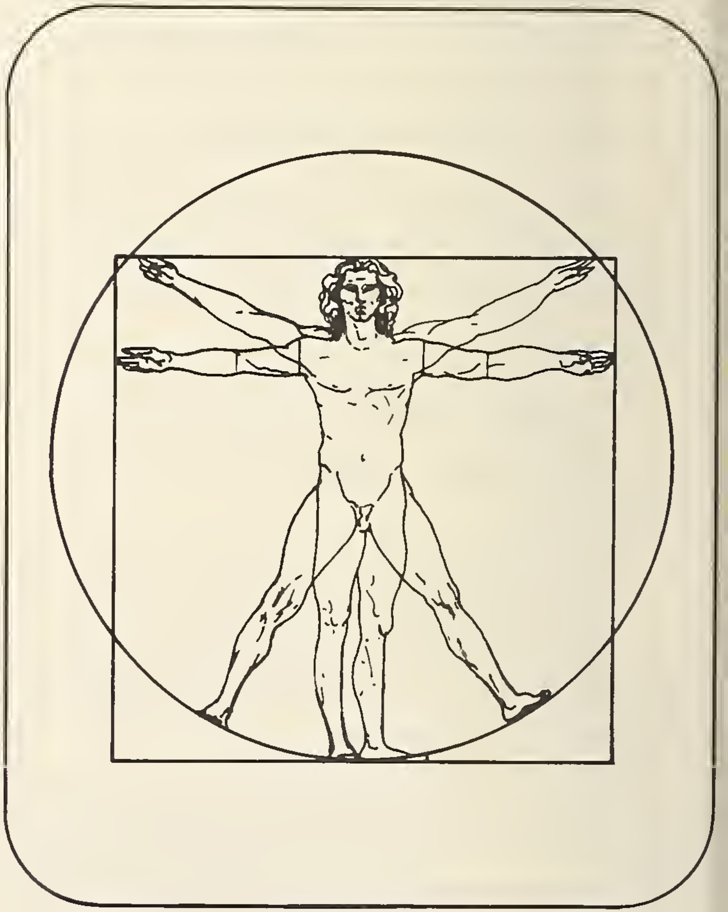

Figure 4

That was the first "national" standard. But unfortunately, this method worked differently from country to country. Figure 5 shows that the foot could vary from 279 mm in Mexico to 513 mm in Italy - and this was even before Mussolini. Incidentally, the Swiss foot happened to be exactly modular, 300 mm or 3 M.

THE COMPLEXITY OF STANDARDIZATION

The coordination of components has to be considered one of the most important tasks in building standardization, because components must fit together in a building. Modular coordination, therefore, is of main importance. But, there are also many other matters which need to be standardized. Let us, for example, choose a simple door. There are a lot of things happening around that door which, nowadays, we are endeavouring to standardize.

Figure 6 shows some of the major aspects. Starting with the coordinating sizes 21 M (2100 mm) for the height and 9 M (900 mm) for the width--which are basic--a series of different properties connected with regulations and performance specifications are internationally interesting subjects to standardize. That simple door shows the complexity of standardization and the need for a systematic approach to all these different issues.

THE SYSTEMATIC APPROACH

We have been trying to find out which kinds of structured approaches we need to define what we are going to standardize. One, which has been used in Sweden, is to start out with dimensions, quality and test methods. This is shown diagrammatically in Figure 7.

Another way could be to base the structuring on the different kinds of components as they are defined within buildings, as illustrated in Figure 8.

A SYSTEM OF LEVELS

But this is not enough to illustrate a complete base for structuring building standardization work as a whole.

In Sweden, we have worked out what we call a "system of levels." This system has been tested and applied in our standardization work for many years, and now also has been accepted by ISO Technical Division 3 as a tool to be used in international building standardization, that is, in all ISO committees concerned with building matters, materials, etc. The concept is summarized in Figure 9.

In building standardization, the most important aspect is modular coordination, because that technique provides us with the framework to standardize components so that they fit together in buildings. An example--dimensioning of windows--will show how this system is used.

On Level 1, Fundamental Standards Dealing with General Principles - we have the basic module, 1 M = 100 mm, the multimodules 3 M, 6 M, 12 M, etc. We also have a standardized series of preferred modular and multimodular dimensions, from which sizes may be chosen for special needs.

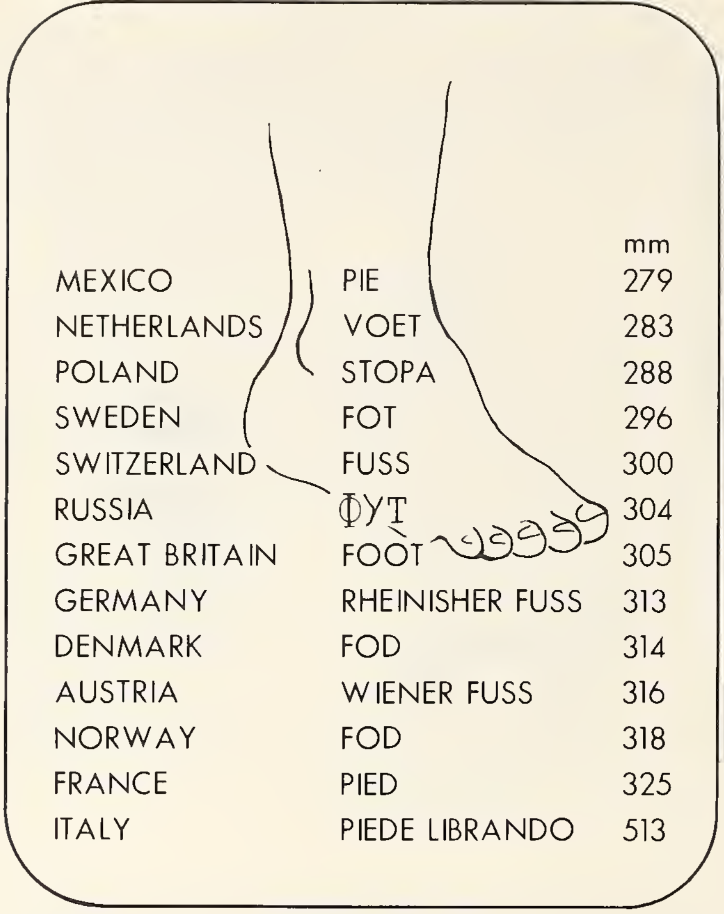

Figure 5

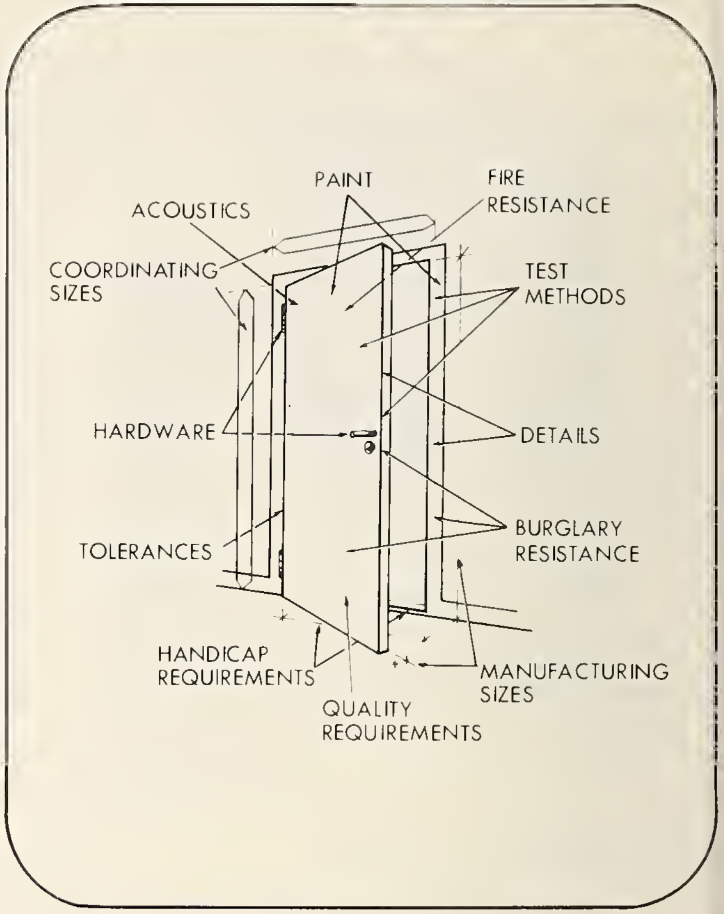

Figure 6

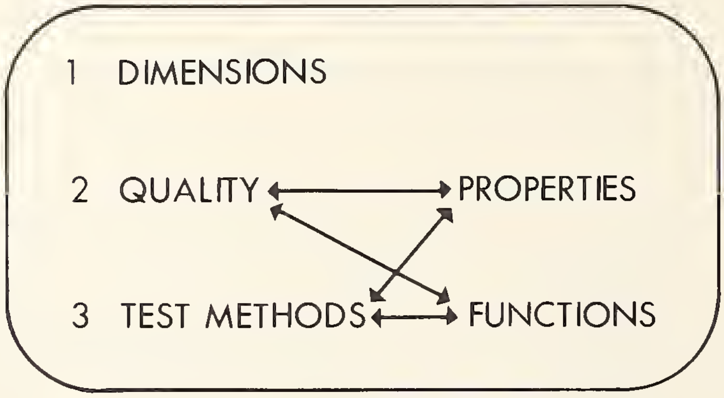

Figure 7

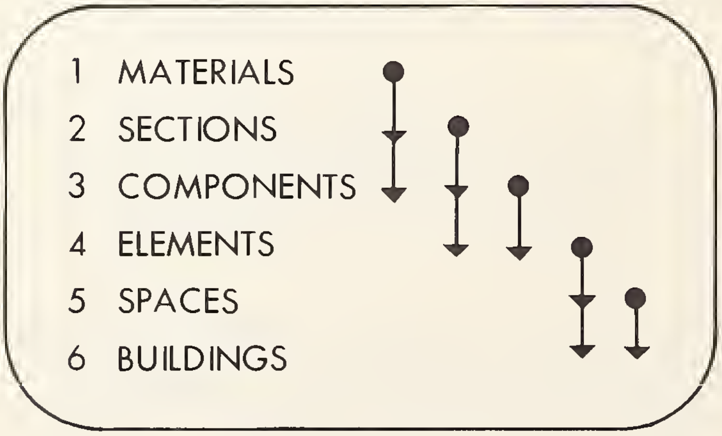

Figure 8

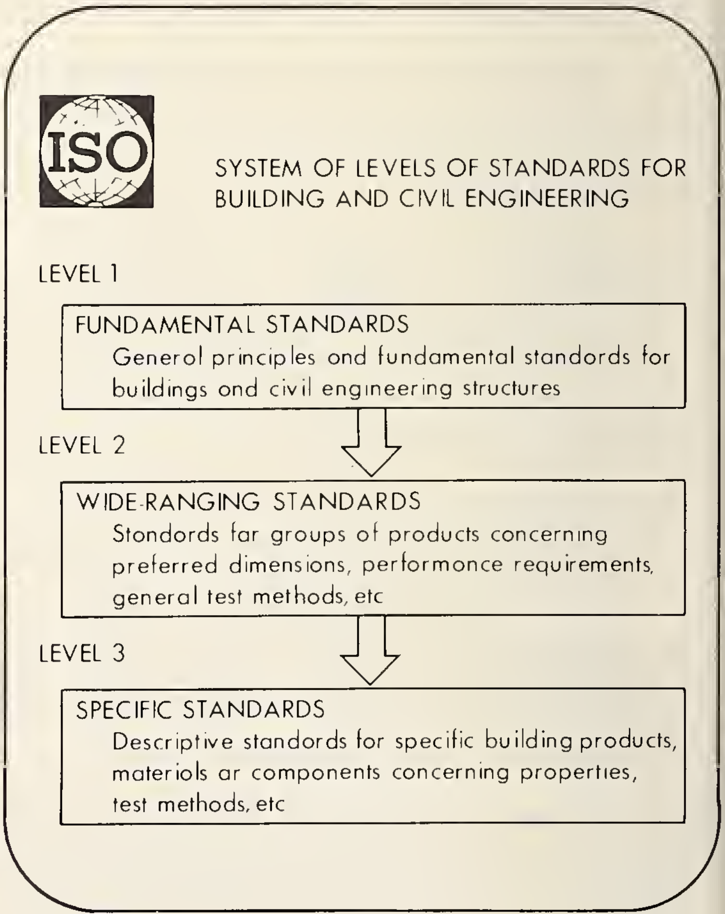

Figure 9

On Level 2, Wide-ranging Standards - the coordinating dimensions--in this case for windows--are chosen from the series on Level 1.

Standards worked out on Level 2 will give coordinating dimensions for all kinds of windows, no matter what materials or constructions are used.

On Level 3, Specific Standards - the standardization can be more detailed, such as giving work sizes and tolerances for wooden windows.

The systems of levels has wide flexibility in its application on various matters of standardization. Used for test methods, general principles for testing may be given on Level 1, standards for test methods which are common for a group of materials or components on Level 2, and specific methods for special properties, materials, etc., on Level 3. The system also may be used in the arrangement of the standardization within or between committees subcommittees, and working groups.

As already mentioned, the system of levels is a tool for standardization, where a standard on a higher level is characterized by its higher "durability" compared to a standard on a lower level. As a consequence, a standard on a lower level should never be established in contradiction to existing standards on a higher level within its domain.

This provides for order in standardization and assists in steering the work in a logical and practical way.

PATTERNS OF STRUCTURING STANDARDIZATION WORK

The three different ways of structuring the standardization work outlined earlier can be assembled in a three-dimensional grid. On one axis, you have materials and components; on the second, dimensions, quality and test methods; and on the third, the system of levels. This is shown graphically in Figure 10.

It now becomes possible to use this grid in order to illustrate any subject which we intend to standardize. If we take "Modular Coordination," it is only a question of dimensions operating on Levels 1 and 2, indicated in Figure 11.

"Concrete beams" represent another example. This subject represents a section dealing not only with nominal dimensions but also with work sizes and tolerances, indicated in Figure 12.

"Windows" fall into the category "components" on Levels 2 and 3. The standards will comprise dimensioning, quality requirements, and test methods. Using the same three-dimensional matrix, this is shown in Figure 13.

Now you may ask: What is the use of all this? For what purpose do you need such a system?

We have found that this is a good tool when we are discussing how to organize the work to ensure that it is not duplicated in another sector. So, without preparing a drawing for each subject, we have the evidence and we can easily define various subjects and what is to be done.

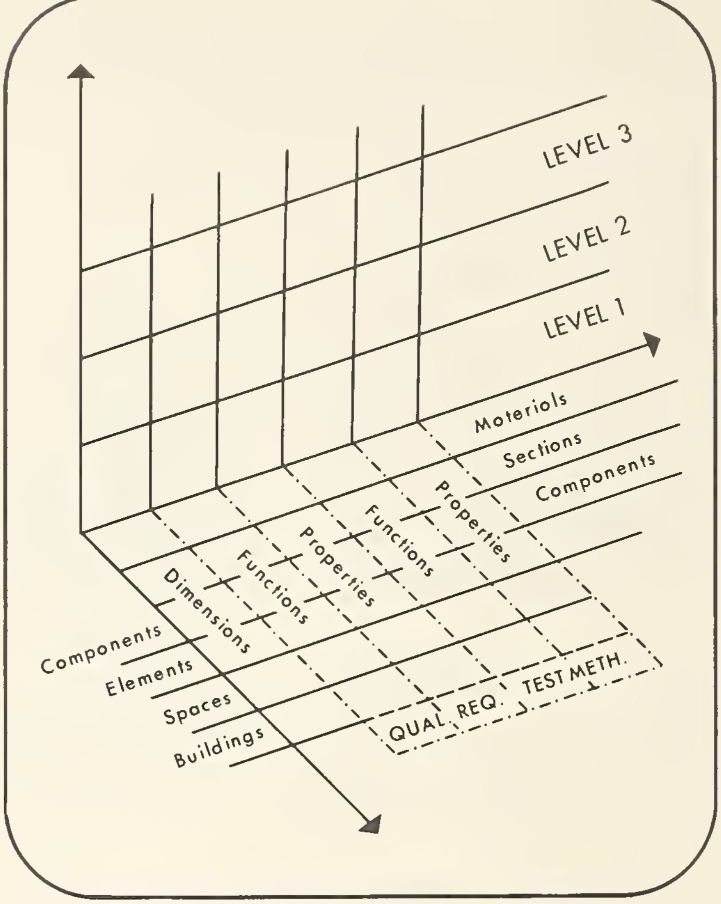

Figure 10

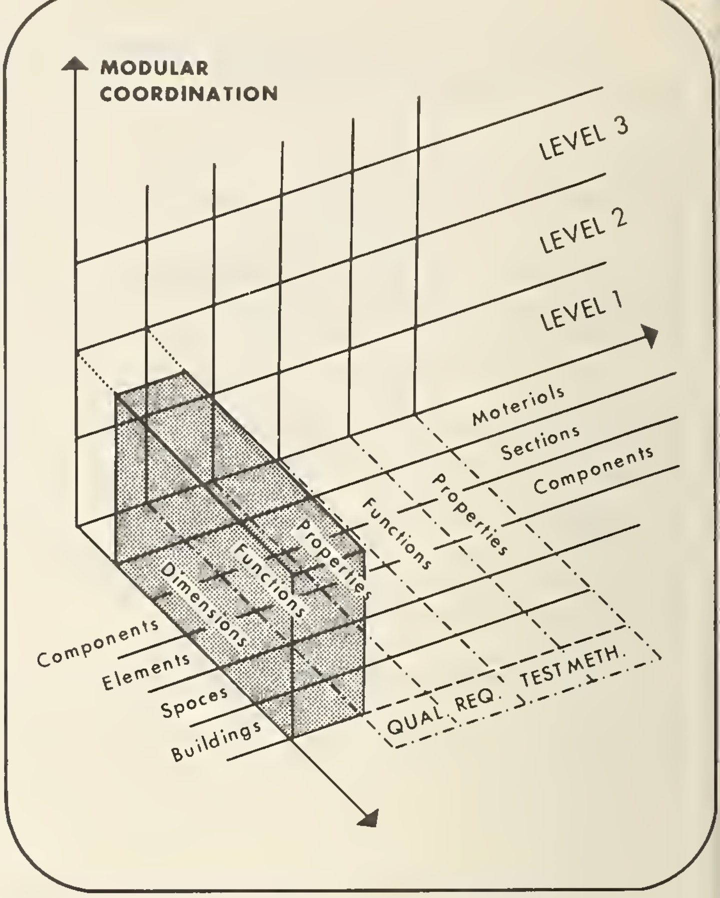

Figure 11

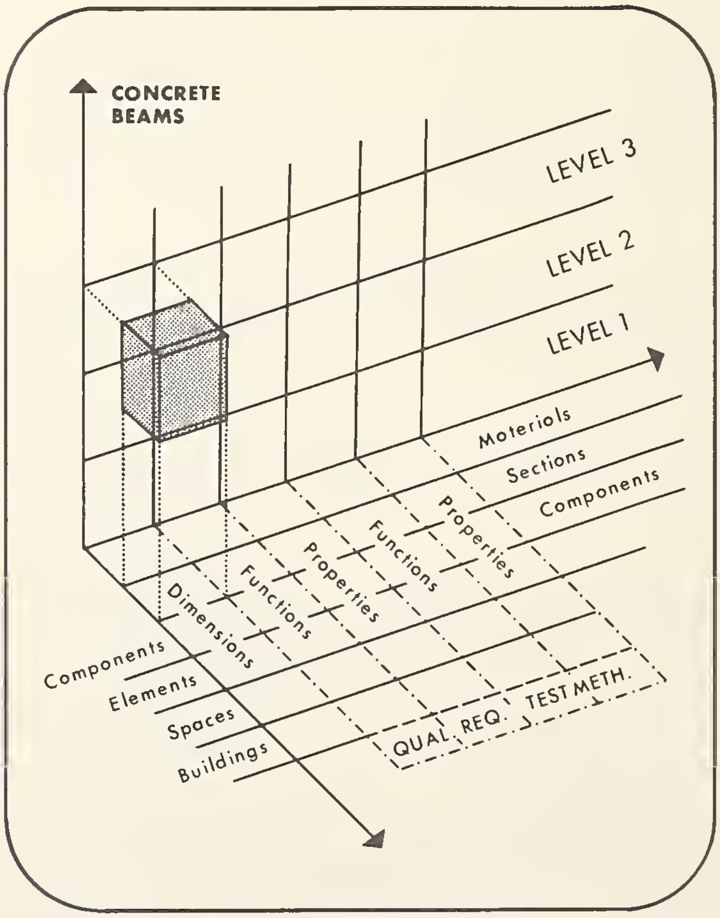

Figure 12

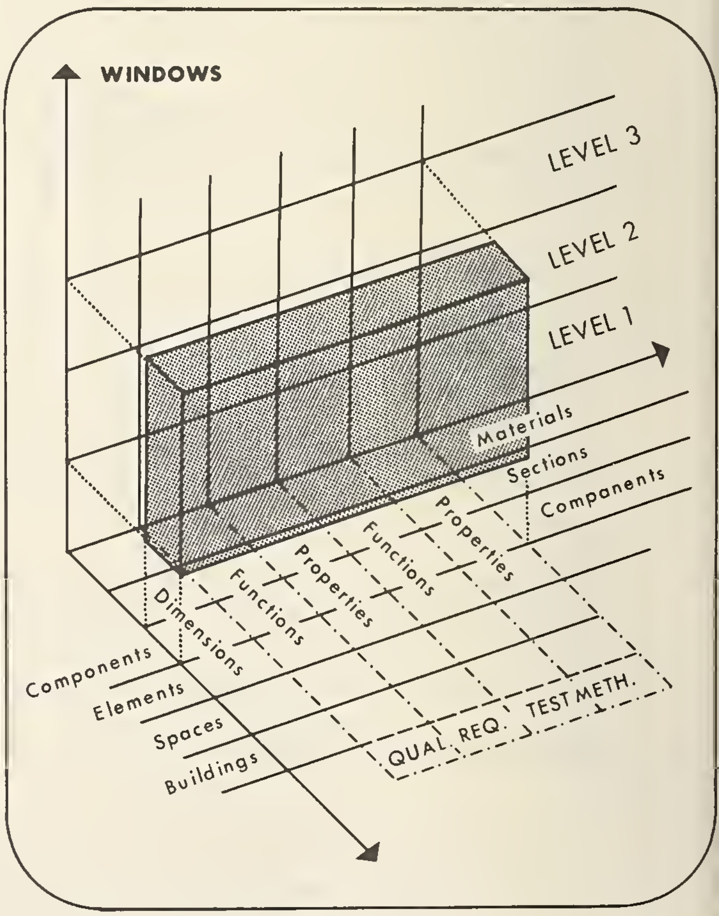

Figure 13

BUILDING STANDARDIZATION IN SWEDEN

The Building Standards Institute (BST) is a Division of SIS - the Swedish Standards Commission. The BST is an independent organization and works with its own funding, and so do the SIS divisions for the mechanical field, the metallic field, and the electrical field. Special committees within SIS standardize matters which are not dealt with in the four divisions.

In the beginning, most of the finances for building standardization came from industrial grants. These have contributed less and less of what we need. So today, about 75% of the grants come from the Council on Building Research, which gets its funds from a special tax levied on contractors' work. The industrial grants amount to 12%, we get 6% from the government, and the remainder--9%--is the income from sales of publications. In all, it amounts to 4.2 million kronas or approximately 1 million U.S. dollars per annum. This is shown in Figure 14.

THE SWEDISH APPROACH TO INTERNATIONAL STANDARDIZATION

Lennart Bergvall mentioned our work in ISO, the International Organization for standardization.

The listing shown in Figure 15 can be perceived, perhaps, as some kind of ladder where the final goal is to get global standards.

National standardization is carried on in committees which are subdivided into working groups. As soon as a project is started on the Nordic level within INSTA--which is a regional sector similar to COPANT and involves participation from Denmark, Finland, Norway and Sweden--we principally give up the national work and have the Nordic matters surveyed by a national reference group. The Nordic committees within INSTA have a similar task: to survey activities going on internationally in ISO, and CEN, which is the European Standards Committee.

The CEN, which was set up to harmonize standards between the European EFTA and EEC countries, more and more has become a tool for the European Common Market, sometimes doubling up on the work in ISO--which does not make things easier. The Nordic policy, therefore, as far as possible, is to contribute to the ISO work and to avoid starting projects in CEN within fields already covered by ISO.

SWEDISH INVOLVEMENT IN INTERNATIONAL STANDARDIZATION

Below is a list of ISO and CEN committees and working groups for which Sweden holds the secretariat:

ISO	TC 10/SC 8	Building Drawings
	/WG 4	Plumbing, Heating, Ventilation, Ducting
	/WG 7	Surface Symbols. Hatching
	TC 59/SC 1	Dimensional and Modular Coordination
	/SC 4/WG 2	Measurement Methods for Building
	/SC 6/WG 4	Stairs and Stair Openings
	/SC 11	Kitchen Equipment
	/WG 1	Physically Handicapped
	TC 77/WG 19	Abestos Cement Siding Shingles
	TC 89/WG 6	Fibre Building Boards: Determination of dimensions
	WG 8	Fibre Building Boards: Technological Properties
	WG 11	Fibre Building Boards: Quality requirements
	TC 92/WG 14	Fire Test for Ventilation Ducts
	TC 151/WG 7	Particle Boards: Dimensions
	TC 162/SC 1	Doors and Windows
	TC 163	Thermal Insulation
CEN	TC 90	Climatic Zones

Without boasting, I would say that this is quite a lot for a little country like Sweden. However, we have only taken secretariats in areas where we have a special interest or where we think we can make a major contribution to international standardization.

Of course, Subcommittee 1 of ISO Technical Committee 59 on "Dimensional Coordination," which is chaired by Mr. Bergvall, is one of the most important committees within the building sector.

Within TC 59 there are other subcommittees such as SC 11 on "Kitchen Equipment." This subcommittee has issued an international standard on Level 2, stating the modular dimensions of the kitchen equipment, without going into any details.

TC 162, "Doors and Windows," is a new committee. Sweden has the subcommittee for doors, and Norway the subcommittee for windows. These subcommittees will be concerned not only with dimensions, but with the entire performance. Within CEN, a large committee is working on test methods for doors and windows. We will try to get this work into ISO as soon as possible, because we believe that it is more practical to have it assembled there than to have the secretariats in different organizations and countries.

Eighteen months ago, we started an ISO committee on thermal insulation, TC 163, which was the first full technical committee serviced by Sweden. At the inaugural meeting in Stockholm, delegates from 13 countries attended. Among the attendees were five delegates from the United States and six liaison organizations. We expect that committee to develop many important standards within the next few years.

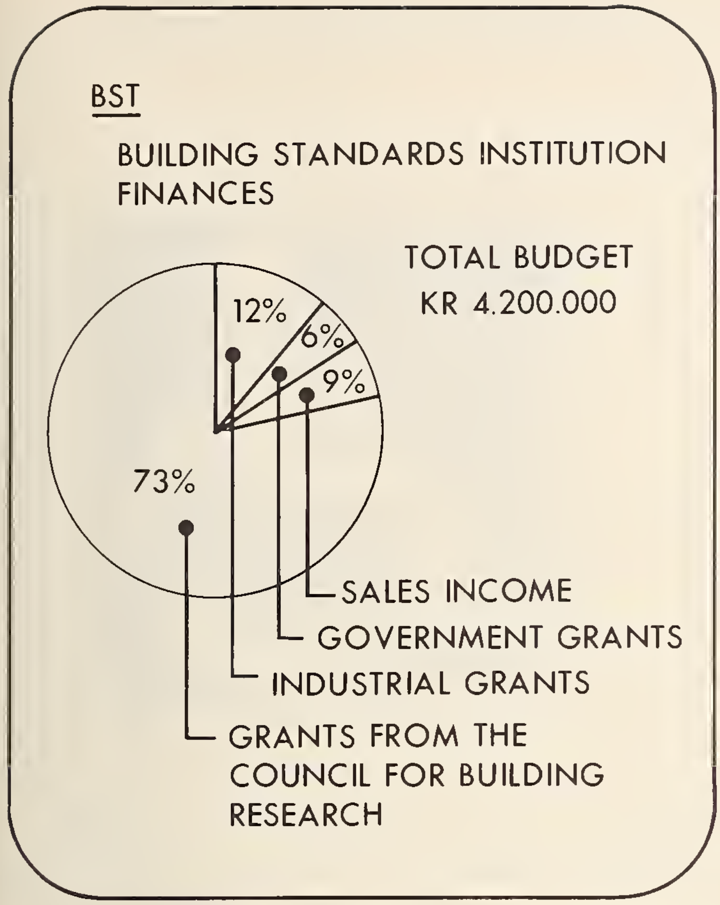

Figure 14

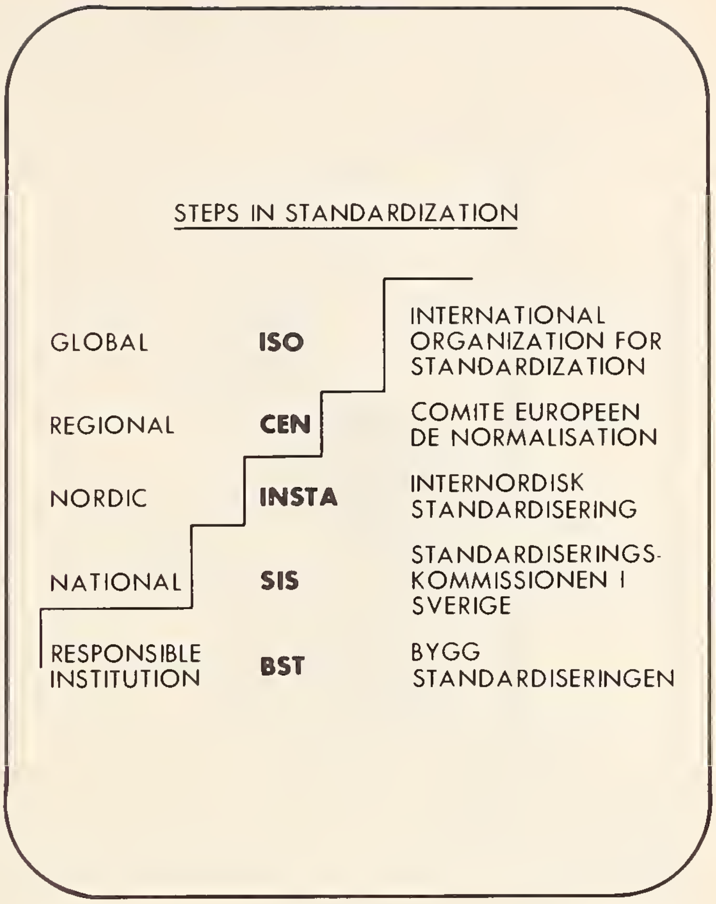

Figure 15

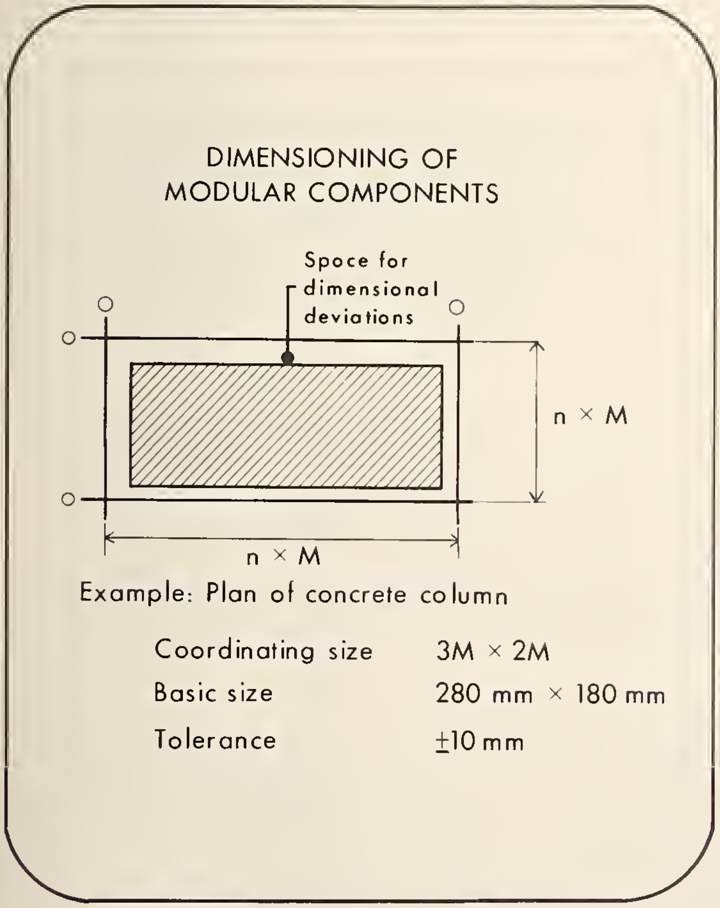

Figure 16

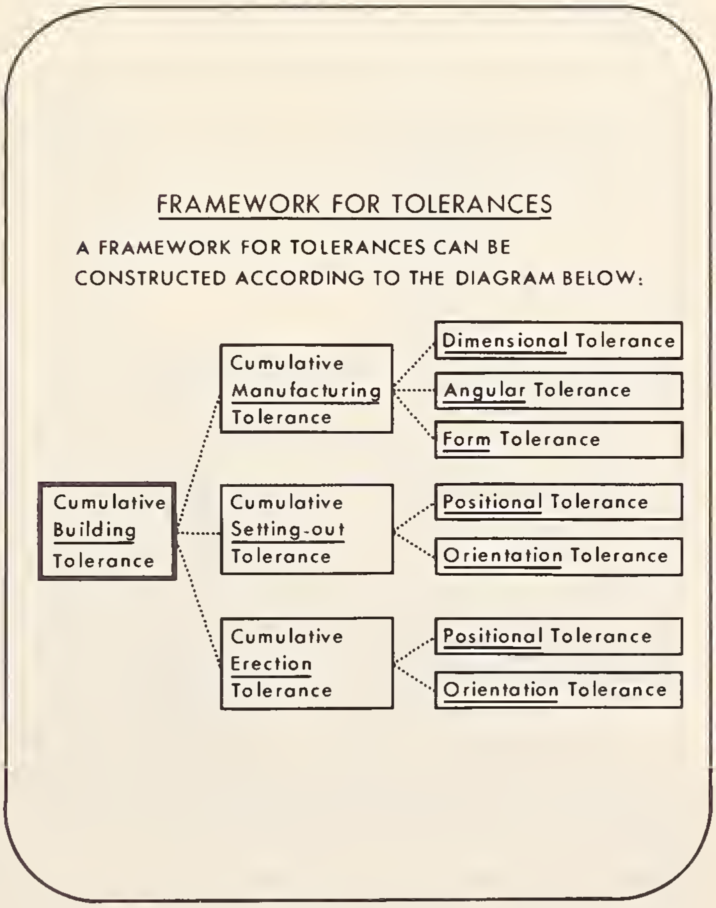

Figure 17

In his lecture, Lennart Bergvall touched on the problem of tolerances. In this field, a Swedish contribution has been presented within ISO that is now on the way to being accepted as an international standard.

Figure 16 is a simplified illustration on this subject.

A component placed within its modular space has to be joined to its surroundings. This raises the need to calculate necessary tolerances on both sides of the modular grid. The framework which has been developed in Sweden can best be illustrated in a table, shown as Figure 17, depicting the different groups of tolerances that occur in the building field.

In addition to the manufacturing and assembly tolerances used in the mechanical field, the building field needs special tolerances for the setting out and erection of components. Based on these concepts, the standard provides all formulas for the calculation of relevant tolerances in building.

The questions concerning the physically handicapped are considered highly important in our country. When ISO/TC 59 recently set up a special working group to deal with general questions concerning requirements for the handicapped during standardization in building, it was quite natural that Sweden was entrusted with the secretariat. But even before that, Swedish contributions in this area had been approved by ISO. The international symbol for facilities for the handicapped, shown in Figure 18, was a Swedish proposal to be inserted in ISO-standards for all lifts which permit the transport of wheelchairs.

We also are working with standards to avoid burglary. This work is continuing with authorities and insurance companies. There is now a Swedish standard--the first one for doors--which not only sets the requirements for locks and hinges, but also sets requirements for the installation of the door itself. In many instances there is no need to open the door at the lock. There are other ways to get through, as illustrated in Figure 19.

SOME REFLECTIONS ON INTERNATIONAL STANDARDIZATION

ISO technical meetings seem to have their own special pattern and sequence. When all questions of procedure and discussions concerning definitions are brought to an end, and the main point of the meeting is the next item on the agenda, these patterns are more clearly shown. At the same time insuperable obstacles seem to arise. A typical example is the determination and resolution of an international set of general coordinating dimensions in building.

One delegate (A) accepts the dimensional series proposed by the secretariat with the addition of some dimensions which are common in his country. Another delegate (B) cannot accept the proposed series at all, and he insists upon entirely new values. A third delegate (C) wants to introduce a new basic module. The fourth delegate (D) pretends to agree with A's proposal provided that some of the values are shown in parentheses. And, the merry-go-round has started.

Figure 18

Figure 19

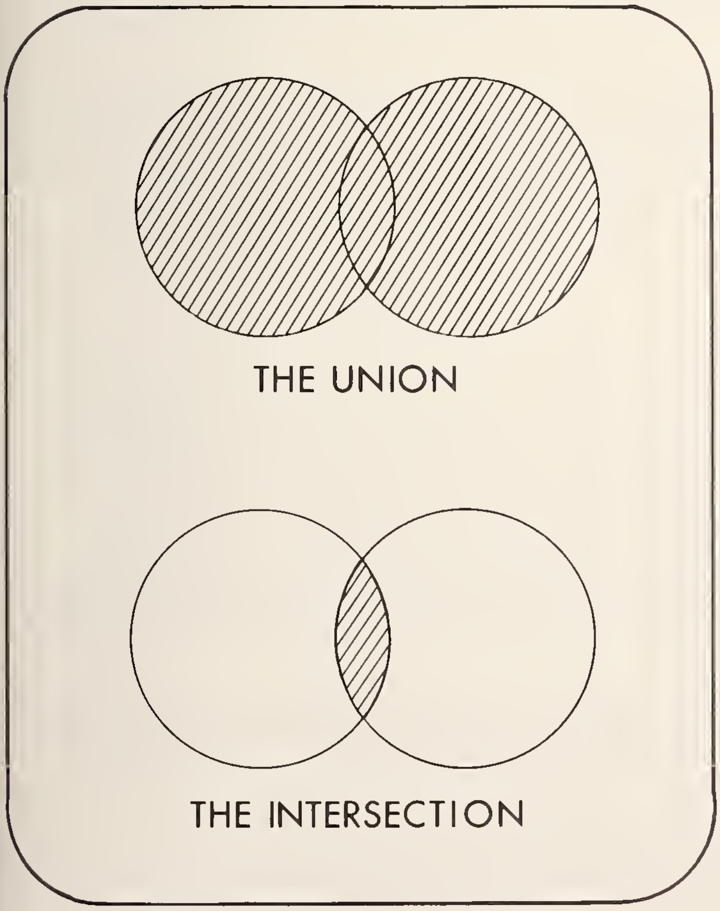

Figure 20

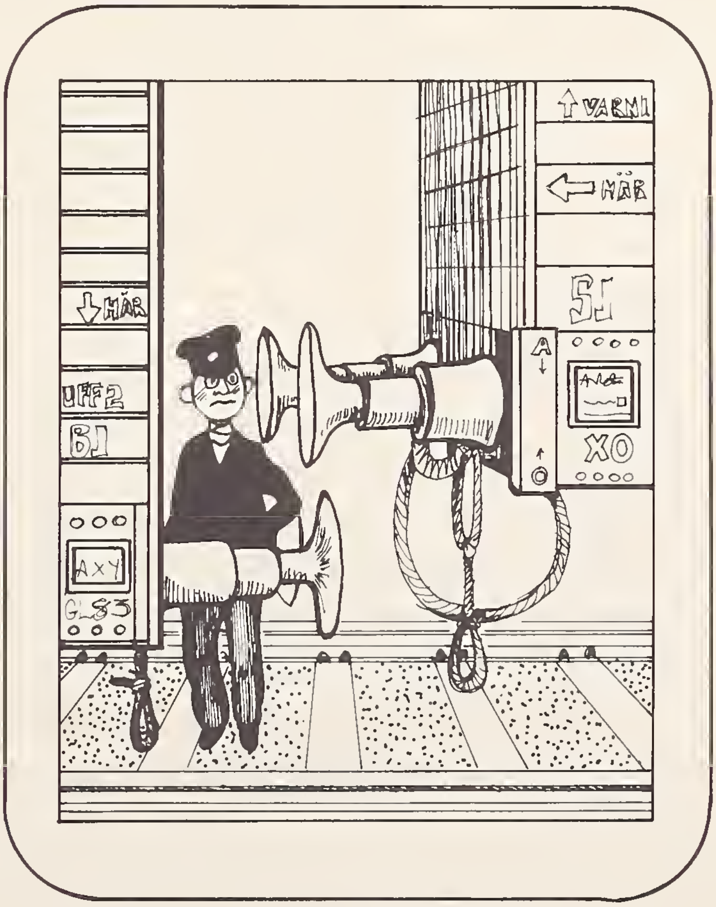

Figure 21

In principle, there are two possibilities of selection which can be applied in standardization. Within the algebra of sets, nowadays taught at an early stage in schools, they are defined as the UNION and the INTERSECTION, shown graphically in Figure 20.

To choose the union in standardization means to accept all the values proposed. This would satisfy every delegate who then could be happy knowing that, in any case, his own values are safe within the series, even if this has been done at the cost of the same favor for all other delegates. There are examples of such standards within ISO. But this no longer means standardization, and still less the limitation of variants. Rather it should be called an internationally-agreed upon catalog.

In contrast, a selection based on the principle of intersection will only comprise those values which are common to different countries; i.e., the very limited range, which is acceptable to everyone. Provided that such values do exist in a sufficient number to establish a useful but limited series, the principle of intersection constitutes the perfect basis for international standardization.

However, the reality is generally more complicated and often results in a compromise between these two extremes. Normally, work on the compromise solution takes place during the teabreaks, which interrupt the meeting at regular intervals.

As far as I can judge from experience, from a technical point of view it is always advantageous in international standardization to steer towards the intersection principle (that is to include only those values which are common to different countries), and to admit as few exceptions as possible.

This is an example of obstacles that frequently face us in trying to cooperate internationally. And, most probably, we will meet them again in our future work. But, I believe that people become aware more and more of the need to reach agreements even if it is at the cost of a small national sacrifice.

CONCLUDING REMARKS

I would like to conclude by saying that I personally believe that with all of the problems we see arising around the world, particularly in the building field, we will never be able to meet the demands in the future without well-developed international standardization. In other words, we must arrive at a common and universal technical "language." Here in the United States you are on your way to metrication. As a consequence, you will have to apply the SI units. Being an optimist, I also hope that you will accept modular coordination.

I will finish this expose showing you that there are also optimists of another kind like the one shown in Figure 21.

INTRODUCTION OF HANS MILTON

CHARLES MAHAFFEY

Mr. Hans J. Milton is the Assistant Secretary for Housing Research in the Australian Government Service, and he is on loan to us until October 1977. He is serving as a Technical Consultant to the National Bureau of Standards on metrication and dimensional coordination. Mr. Milton holds not only a degree in architecture, but master's degrees in building science and in business administration. He was the Director of Metric Conversion in the Australian Department of Construction (Works) from 1970 to 1974, and the Chairman of the Government Construction Sector Committee of the Australian Metric Conversion Board. He was one of the prime movers in the very successful change to a metric building environment in Australia, which was carried out with enthusiasm and pragmatism.

Hans Milton has written a number of books and many articles and technical papers dealing with the issues before us. He will talk about dimensional coordination--the precedents and issues in front of us.

METRICATION - THE OPPORTUNITY FOR AN INDUSTRY-WIDE SYSTEM OF DIMENSIONAL COORDINATION: PRECEDENT AND ISSUES

HANS MILTON

In addressing the twin topics metrication and dimensional coordination in building, we probably are dealing with the two most significant issues before the construction community in our time; at least that is what I believe.

Firstly, there is the transfer from the customary measurement system to an internationally agreed upon system of measurement - SI (the International System of Units). This transfer involves a change of the entire technical data base of the construction community to new values and new units of measurement. But SI, a decimally-based system of coherent units, becomes even more useful to us if it is allied with a set of preferred numerical values. For example, it is generally much more simple to work with a number such as 100, than it would be to use 101.6, 102, or 110.

The second issue specifically revolves around the selection of such preferred values for the measurement of length in building design, production, and construction, and for the coordination of preferences in a systematic approach which extends through all sectors of the construction community. Dimensional coordination deals with "preferred dimensions" in building design, and related "preferred sizes" for building products. The term modular coordination is widely used to describe the discipline, because such coordination is generally derived from selected preferences of a basic module.

DIMENSIONAL COORDINATION AS AN "OPEN SYSTEM" - AND THE ALTERNATIVES

The objective of the systematic selection and coordination of preferences is to develop an "open system" in which the selected dimensions serve to coordinate the geometry of a wide variety of building types and their elements, with a wide variety of products and assemblies from different sources of supply.

Dimensional coordination, if properly applied, will benefit all parties in building design, production, and construction; but, it needs to be properly understood, including its limitations, if it is to become an effective integrating device for the construction community. To better understand the concept of an "open system," we must understand the extremes that lie on either side of it - the "closed system" on one hand, and the completely "free," or "random" approach on the other.

In a "closed system," the designer(s) and manufacturer(s) match precoordination with prefabrication. The result is that the various needs that arise in a particular building type, such as schools, hospitals, apartment buildings, etc., can be met from a small catalog of parts and sizes, specifically designed and produced for the "building system." Some traditional building systems have been very effective, because building products could be fabricated not only with lower cost, but also with better quality derived from repetition, and better product development as well as quality control in a smaller product line. On-site productivity is improved as the learning curve of the site personnel improves because the assembly processes are also repeated and can be standardized. Against these appealing advantages, there is the problem that "closed systems" are made to order for specific building types. This does not allow for ready interchangeability in construction applications.

Historically, we have always had available to us the "random" or "special project" approach, in which each building had its own individuality. In this approach, which can hardly be called a "system," the architect selects and specifies an "independent" set of design dimensions, requiring that building products serve the requirements of design regardless of the cutting, fitting, special components, and waste of resources that accompany this approach. Since each project generates its special dimensions for products used in the vertical plane, the lack of standardization of floor-to-floor heights in multi-story building is a good example of the random approach.

It is only in the "famous" examples of the free design approach that we begin to appreciate the cost factors associated with the random approach. In Australia, we found that one can get an excellent Opera House for $125 million, while the initial cost limit of the client - the Government of the State of New South Wales - was $7 million. This is no mean order of difference.

Dimensional coordination is applicable to most buildings, but it works best in building design and construction involving predominantly rectilinear structures using rectilinear components.

Dimensional coordination represents the greatest single opportunity in the eventual metrication program for the U.S. construction community, because it provides the tool by which all sectors of that community can acquire a common reference framework for linear dimensions, based on dimensional preferences. For once, all sectors will be able to talk a common language of dimensions.

INTERNATIONAL DIMENSIONAL COORDINATION

Previous speakers have dealt in some detail with international "modular coordination," which is dimensional coordination employing the internationally-recognized basic module of 100 mm (indicated by the symbol "M"), as the fundamental unit of size in coordination.

Modular coordination, based upon a 4-inch (101.6 mm) unit of size, was originally pioneered in the United States during the 1920's and 1930's; and in 1945, the American Standards Association (now ANSI) approved the 4-inch module as an American standard suitable for the coordination of dimensions in building. In a different approach, Professor Neufert led Germany into a 125 mm, or octametric module.

But in the 1950's, eleven European countries joined in efforts to establish a common module and approach to coordination. The countries of Western Europe coalesced their thinking into a form of multi-national coordination employing the 100 mm module. (Some European countries refer to this unit of size as 10 cm, but the SI recommendations for linear measurement accord the millimeter complete preference over the centimeter.) The 100 mm module, so close to but different from the 4-inch module, now has been accepted worldwide as the basis for the standardization of dimensions and sizes in building. This also includes the countries of Eastern Europe. In the study of European precedent in dimensional coordination, we found that the move to modular and preferred dimensions and sizes had to be accomplished against a background of traditional sizes and practices. Without the catalyst of a complete change in the measurement system, such a change is much slower and more difficult than the change now before the United States, where the transfer from customary measures to metric (SI) measures will bring with it an entirely new set of preferred values. Metrication facilitates dimensional coordination based on the international module of 100 mm and selected multiples.

Thus, we can look to European precedent and approaches for the statement of theory and principles of dimensional (or modular) coordination, because that is where they have been developed to a very high extent. But if we come to the practical application, particularly in conjunction with metrication, then we would be best served by studying the precedent in those countries which have preceded the United States in metrication, and have attached a firm commitment to dimensional coordination to the change to a metric building environment.

INTERNATIONAL PRECEDENT IN METRIC DIMENSIONAL COORDINATION

Britain

Britain was the first country to combine metrication and dimensional coordination in building. Many of you have heard of the British experiences; some of you, I know, have visited Britain and have studied the approaches to and problems encountered with metric dimensional coordination. Britain was in a difficult position in its voluntary change to a metric building industry; on one hand, it did not want to alter traditional approaches and requirements too drastically, and on the other it wanted to link up with the principles and theoretical concepts that had been developed by the European nations in its immediate market area.

This was no easy adjustment. Traditional requirements had emphasized the foot [305 mm]; multiples such as 3 feet [914 mm] for panel sizes, with associated subdivisions such as 18 inches [457 mm] for stud spacing; and subdivisions of the foot, such as 3 inches [76 mm] and 6 inches [152 mm], rather than 4 inches [102 mm] and 8 inches [203 mm]. And this did not fit too well with the international precedent at that time.

So Britain departed from the international recommendations on two counts. Firstly, it instituted a first preference dimension of 300 mm, rather than 100 mm, which was not in line with agreed and accepted international principles. Secondly, it developed "dimensional coordination" rather than "modular coordination," (the latter term is not used in Britain), as a system for "the application of a range of related dimensions to the sizing of building components and assemblies and the buildings incorporating them." In that system, there is a little more room for non-modular dimensions. The British have done some significant work in the area of coordination of dimensions, both in theory and in practice, and there is a lot of useful precedent - both in what to do, and what not to do. And they have prepared some excellent documents dealing with dimensional coordination, their only failing being that there were too many of them which, in turn, frightened off a lot of people.

South Africa

Chronologically, South Africa followed Britain with a national metrication program, but it went a different route. South Africans followed the approach "let us metricate as quickly as possible, and when we have achieved a metric environment, we can then start to settle some of the other issues, such as preferred dimensions and sizes; after all, the Europeans have done it that way." You can see why that approach is not too successful. It meant that most of the groups associated with the building industry had to make two changes rather than one - they had to change to metric measurement first, and then to dimensional preferences and dimensional coordination at a later stage.

Australia

Australia's planning for a metric construction community began at the end of 1970, and the bulk of the changes to a metric building environment were implemented between 1974 and 1976.

By nature of their geographic isolation, Australians have had to be pragmatists from way back. So, they evolved another approach to dimensional coordination. Right at the beginning, it was realized that it would be undesirable to have two terms - dimensional coordination, and modular coordination - so neither was used. In Australia, the descriptions "preferred dimensions (for building design)," and (related) "preferred sizes (for building components)," were employed. Attention was drawn to the word "preferred," because it represented the central issue in a system of coordination.

To me, all of standardization can be summed up in one sentence and that is: "Standardization is the positive balance between what is obtained and what is given up in the interest of a more efficient performance." Thus, if we standardize in building, what we get must be worth more than what we give up. By drawing attention to the word "preference" in both design and product manufacture, we suggested that both groups had to yield a little in order to gain more. Designers had to refrain from completely random dimensional choices if they were to play their part in the development of a system of preferred dimensions in building that was harmonious with preferred product sizes. Product manufacturers, in turn, had to voluntarily abandon some of the random sizes previously produced to meet real or assumed demands which were in conflict with the concept of preference. Or else, they had to emphasize that "specials" incurred a cost premium. When we became more deeply involved in the issues, we found out that the giving-up process was not really as difficult as it tended to look from the distance.

The most significant new ingredient in the Australian approach was in "marketing" dimensional coordination. We realized that, if people were to be confronted with abstract, technical concepts in the introduction of metric dimensional or modular coordination--such as having to learn special notation, special symbols, special techniques of drawing, and a large glossary of special terms--then they would rather be without it.

Therefore, we developed a pragmatic approach, in which the first objective was to create an environment for the appreciation of "preferences," especially preferred sizes. We realized that multimodular dimensions of 600 mm and 1200 mm were important preferred and integrating dimensions, because 600 mm integrates the 300 mm and 200 mm units of size. We shifted the emphasis to "preferred metric sizes of building components," in the realization that such components would enable designers to work in a preferred metric environment, regardless of any superimposed system of coordination, such as a dimensional or modular order. We instinctively felt that the availability of preferred metric components would channel the construction community into more selective and more appropriate preferred solutions - rather than the other way round.

Secondly, we stressed that even a partial application of (the principles of) dimensional coordination in design and construction would be better than no application at all. And, by giving designers an appreciation of preferred dimensions, and producers an understanding of the desirability of a one-time change to preferred sizes, we chose the most persuasive and least coercive track. Finally, we stressed that those groups in the construction community that were best equipped and most capable to use the complete concept of metric dimensional coordination, should and would do so naturally, and would use it to great advantage.

Canada

The United States is extremely fortunate to have a metric laboratory to the north; that laboratory being Canada. The Canadian construction community is committed to a metrication program with an M-Day of January 1, 1978, and the achievement of substantial dimensional coordination is one of the objectives of that program. In the recommendations on the subject of dimensional coordination, Canada has coalesced many of the international approaches, (primarily British and European precedent) with a fair flavoring of Australian precedent. It is a bold assertion to state that many Canadian metric standards for the construction community are either mothered or fathered by Australia; they seem to have at least a 50% Australian component. But this should be naturally so; not because Australia was any more capable than other countries, but because in its approaches it gained the benefit of close scrutiny and harmonization of the approaches of others beforehand, to which a good deal of pragmatism was added in order to derive harmonious and acceptable solutions. Canada has added slightly more sophistication in some areas.

Since practices in the Canadian construction community are closely allied with those in use in the United States, it can be expected that many relevant and useful lessons can be learned right here in North America. This applies particularly in terms of dimensional preferences. Canada has echoed a strong preference for 600 mm and its multiples as preferred coordinating dimensions. The National Standard of Canada, CAN3-A31.M-75 "Series of Standards for Metric Dimensional Coordination in Building," outlines dimensional preferences for buildings and building materials. With the Canadian M-Day not too far away, the United States will soon be in a position to monitor and assess how well the Canadian proposals work.

METRIC DIMENSIONAL COORDINATION - SOME OF THE ISSUES THAT WILL ARISE ON THE WAY

The major question that the U.S. building community faces is: "How do we get to a dimensionally coordinated metric building environment in the most efficient and effective manner?"

And to get there, it will have to simplify some of the abstract concepts in order to make the system more palatable and acceptable to all parties. The U.S. has to show that the coordination of dimensions is practicable in design and construction, as well as in production. It has to mount an educational program. This has to be done by design groups, as well as producers' associations, and it must be done during the introductory phase of metrication and metric dimensional preferences. The U.S. has to market the concept in such a way that alternatives become less acceptable than they have been. In Australia, we paid a great deal of attention to demonstrate new concepts in a proper perspective.

The issues are best illustrated by way of a series of examples.

1. Preferred Dimensions and Their Recognition

In Australia, we found that designers had had considerable difficulty in visualizing modular magnitudes in a customary 4-inch modular environment. Designers could not even tell, straight off, how many modules there are in 5' 8", which is a most common dimension since there are many people who are 5' 8" tall.

The first weakness in the customary system of dimensional preference is that our recognition power is reduced, because we are dealing with two different measurement units - feet and inches - at the same time. It is not immediately apparent that 5' 8" contains 17 modular (4-inch) units. Secondly, there is no real recognition as to whether that dimension is a better or worse dimension that 5' 4" or 6' 0".

By comparison, in the transfer to a metric building environment, any person will be able to tell immediately that 1700 mm equals exactly 17·units of the basic module of 100 mm. But equally significant is the fact that the multiplier 17 represents a prime number, which is not nearly as useful in terms of divisibility as 18 or 16. We know that 1800 mm can be divided into whole multiples of 900, 600, 300 and 200; and that 1600 mm is divisible by 800, 400 and 200. Thus, the preferred dimensions that lie on either side of 1700 mm, namely 1800 mm and 1600 mm, immediately can be recognized as superior values.

This was one feature we concentrated on in the establishment of dimensional preferences for metric building in Australia. In the design process, as well as the construction process, we principally deal with two elements - additivity (the addition of components to make up elements and/or whole buildings), and divisibility (the division of the geometric dimensions of building structure into the maximum number of components in preferred sizes to minimize wastage). The use of preferred dimensions and preferred sizes in a metric building environment can be mutually reinforcing, as shown in Tables 1 and 2 on page 40. These are taken from an Australian paper dealing with "The Principles and Practical Application of Coordinated Preferred Dimensions and Sizes in Building Construction," part of which was later adopted in the National Standard of Canada CAN3-A.31.4M-75, "Recommended Metric Coordinating Dimensions for the Sizing of Building Components."

The Tables on page 40 provide a powerful decision-making tool, as they identify quite clearly where the most preferred and useful design dimensions can be found, vis-a-vis those that are preferred in building product sizing. Although developed specifically for Australia, the principles can be utilized in the establishment of preferred dimensions for the U.S. construction community. The important aspect is that, for the first time in the history of the building community, there will be a harmony in the dimensional

[Reduced size extract from a paper by H.J. Milton, entitled "THE PRINCIPLES AND PRACTICAL APPLICATION OF COORDINATED PREFERRED DIMENSIONS AND SIZES IN BUILDING CONSTRUCTION," presented at the Standards Association of Australia Conference on "Preferred Dimensions and Sizes in Building" (Melbourne, Australia, 13 March, 1973), pages 9 - 10].

AN APPROACH TO THE SELECTION OF PREFERRED DIMENSIONS

Preferred building dimensions given in AS 1233/34 and preferred component sizes shown in AS 1224 have been chosen to complement each other.

In the design of building structures, building envelopes and internal spaces certain dimensions are strongly preferred because they provide maximum flexibility for the integration of preferred component sizes indicated in AS 1224

In the approach to the selection of preferred building dimensions outlined below, components and assemblies are grouped in three categories according to site application, and are then ranked according to dimensional preference, as shown in Table 1:

TABLE 1

CATEGORY	Examples of Component Assemblies	Dimensional Preference (mm) 1st	2nd	3rd
1. SMALL COMPONENTS (under 500 mm) - laid in situ	bricks, blocks, tiles, paving slabs	100 200 300 400	50 150 450	25 75
2. MEDIUM-SIZE COMPONENTS AND ASSEMBLIES (under 1400 mm in width) - handled manually	sheets, panels, partition units, doorsets, windows, slabs	600 900 1200	500 700 800 1000 (see Note)	750 1350
3. HEAVY OR LARGE-SIZE COMPONENTS AND ASSEMBLIES (over 900 mm in width) - handled mechanically or by more than one person	precast floor or wall units, panels, window assemblies, door assemblies, precast stairs	1200 1800 2400 3000 3600 (See Note)	900 1500 2100 2700 3300	1000 1400 1600 2000 2200 2500 2600 2800

Note: For the purpose of rationalization, those multiples of 100 mm above 1000 mm which are prime numbers should only be considered where special requirements exist; e.g. 1100, 1300, 1700, 1900, 2300, 2900 mm, etc., constitute a lower order of dimensional preference for components and assemblies.
For purposes of brevity, the Table takes 1st and 2nd preferences to 3600 mm only, and 3rd preferences to 3000 mm only.

The range of options for the integration of equal size components or assemblies into preferred spaces is shown in Table 2. The Table can be expanded to suit particular applications.

The Table shows first and second preference dimensions from Categories 1 and 2 of Table 1, with deletion of 50 mm and 100 mm which satisfy all cases. Major preferences are indicated by a heavy outline around colum

TABLE 2

Design Dimension (mm)	Number of equal-size Components/Assemblies (mm) 150	200	300	400	450	500	600	700	800	900	1000	1200
600 **	4	3	2				1					
700								1				
800		4		2					1			
900 **	6		3		2					1		
1000		5				2					1	
1200 *	8	6	4	3			2					1
1400		7						2				
1500	10		5			3						
1600		8		4					2			
1800 *	12	9	6		4		3			2		
2000		10		5		4					2	
2100	14		7					3				
2200		11										
2400 *	16	12	8	6			4		3			2
2500						5						
2600		13										
2700	18		9		6					3		
2800		14		7				4				
3000**	20	15	10			6	5				3	
3200		16		8					4			
3300	22		11									
3400		17										
3500						7		5				
3600 *	24	18	12	9	8		6			4		3
3800		19										
3900	26		13									
4000 **		20		10		8			5		4	
4200 **	28	21	14				7	6				
4400		22		11								
4500	30		15		10	9				5		
4600		23										
4800	32	24	16	12			8		6			4
5000		25				10					5	

Note: * and ** indicate superior design dimensions because a large numbe of alternatives for the incorporation of equal-size components exi
The Table can be used for both horizontal and vertical dimensions.

system for the two components that influence the built end product - the building designer and the building materials producer.

Another advantage of metric dimensions will be appreciated far better when it comes to divisibility - such as the division of a floor-to-floor dimension into a whole number of stair risers of equal height. With the use of millimeters, the process of division is changed into a simple operation which is accurate to the nearest millimeter, and far more accurate and less time consuming than the same process in customary units involving feet, inches, and fractions of inches. Where floor-to-floor heights are multiples of 100 mm, simple decision tables can be used to clearly point out appropriate and accurate alternatives.

2. The Cognition of Area in Terms of Preferred Dimensions

The conceptualization of areas, and floor areas in particular, in terms of alternative combinations of linear dimensions, always has been difficult. A designer, provided by his client with a floor area requirement of 100 square feet for a room, could easily conceive of room dimensions of 10 feet by 10 feet; or, of 8 feet by 12 feet 6 inches. However, only one of these combinations provides multiples of (4-inch) modular sizes in both directions; and then it is not necessarily the best solution, but only the most obvious one. The question is, how many other combinations of multimodular dimensions will satisfy the required area criterion, or come close to it; say to within plus or minus two percent?

In Australia, to facilitate the transition to preferred metric dimensions, we developed a set of "area matrixes," in which any given area requirement in square meters (as well as square feet) immediately could be resolved into two linear dimensions that are multiples of 100 mm; but <u>only</u> into such dimensions.

Figure 1 contains an example of one of those area matrixes for combination of dimensions ranging from 2400 mm to 4800 mm in one direction, and from 2400 mm to 7200 mm in the other.

For example, if we use a permissible plus or minus two percent variance on an area requirement of 9 square meters (97 square feet), we can recognize at once a whole series of combinations of preferred dimensions, all of which will satisfy the stated area requirement. There are even preferences within preferences, such as combinations of dimensions that are multiples of 600 mm, 300 mm, or 200 mm. The matrix also can be used in reverse, to determine floor areas and general areas in square meters (and square feet) for combinations of linear dimensions that are multiples of 100 mm. This is useful for estimating purposes.

Figure 1

EXAMPLE OF METRIC AREA MATRIX

	2400	2500	2600	2700	2800	2900	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900	4000	4100	4200	4300	4400	4500	4600	4700	4800
	SQUARE METRES SQUARE FEET																								
2400	5.76 62.0	6.00 64.5	6.24 67.0	6.48 70.0	6.72 72.5	6.96 75.0	7.20 77.5	7.44 80.0	7.68 82.5	7.92 85.5	8.16 88.0	8.40 90.5	8.64 93.0	8.88 95.5	9.12 98.0	9.36 101	9.60 103	9.84 106	10.08 109	10.32 111	10.56 114	10.80 116	11.04 119	11.28 121	11.52 124
2500	6.00 64.5	6.25 67.5	6.50 70.0	6.75 72.5	7.00 75.5	7.25 78.0	7.50 80.5	7.75 83.5	8.00 86.0	8.25 89.0	8.50 91.5	8.75 94.0	9.00 97.0	9.25 99.5	9.50 102	9.75 105	10.00 108	10.25 110	10.50 113	10.75 116	11.00 118	11.25 121	11.50 124	11.75 126	12.00 129
2600	6.24 67.0	6.50 70.0	6.76 73.0	7.02 75.5	7.28 78.5	7.54 81.0	7.80 84.0	8.06 87.0	8.32 89.5	8.58 92.5	8.84 95.0	9.10 98.0	9.36 101	9.62 104	9.88 106	10.14 109	10.40 112	10.66 115	10.92 118	11.18 120	11.44 123	11.70 126	11.96 129	12.22 132	12.48 134
2700	6.48 70.0	6.75 72.5	7.02 75.5	7.29 78.5	7.56 81.5	7.83 84.5	8.10 87.0	8.37 90.0	8.64 93.0	8.91 96.0	9.18 99.0	9.45 102	9.72 105	9.99 108	10.26 110	10.53 113	10.80 116	11.07 119	11.34 122	11.61 125	11.88 128	12.15 131	12.42 134	12.69 137	12.96 140
2800	6.72 72.5	7.00 75.5	7.28 78.5	7.56 81.5	7.84 84.5	8.12 87.5	8.40 90.5	8.68 93.5	8.96 96.5	9.24 99.5	9.52 102	9.80 105	10.08 109	10.36 112	10.64 115	10.92 118	11.20 121	11.48 124	11.76 127	12.04 130	12.32 133	12.60 136	12.88 139	13.16 142	13.44 145
2900	6.96 75.0	7.25 78.0	7.54 81.0	7.83 84.5	8.12 87.5	8.41 90.5	8.70 93.5	8.99 97.0	9.28 100	9.57 103	9.86 106	10.15 109	10.44 112	10.73 115	11.02 119	11.31 122	11.60 125	11.89 128	12.18 131	12.47 134	12.76 137	13.05 140	13.34 144	13.63 147	13.92 150
3000	7.20 77.5	7.50 80.5	7.80 84.0	8.10 87.0	8.40 90.5	8.70 93.5	9.00 97.0	9.30 100	9.60 103	9.90 107	10.20 110	10.50 113	10.80 116	11.10 119	11.40 123	11.70 126	12.00 129	12.30 132	12.60 136	12.90 139	13.20 142	13.50 145	13.80 149	14.10 152	14.40 155
3100	7.44 80.0	7.75 83.5	8.06 87.0	8.37 90.0	8.68 93.5	8.99 97.0	9.30 100	9.61 103	9.92 107	10.23 110	10.54 113	10.85 117	11.16 120	11.47 123	11.78 127	12.09 130	12.40 133	12.71 137	13.02 140	13.33 143	13.64 147	13.95 150	14.26 153	14.57 157	14.88 160
3200	7.68 82.5	8.00 86.0	8.32 89.5	8.64 93.0	8.96 96.5	9.28 100	9.60 103	9.92 107	10.24 110	10.56 114	10.88 117	11.20 121	11.52 124	11.84 127	12.16 131	12.48 134	12.80 138	13.12 141	13.44 145	13.76 148	14.08 152	14.40 155	14.72 158	15.04 162	15.36 165
3300	7.92 85.5	8.25 89.0	8.58 92.5	8.91 96.0	9.24 99.5	9.57 103	9.90 107	10.23 110	10.56 114	10.89 117	11.22 121	11.55 124	11.88 128	12.21 131	12.54 135	12.87 139	13.20 142	13.53 146	13.86 149	14.19 153	14.52 156	14.85 160	15.18 163	15.51 167	15.84 171
3400	8.16 88.0	8.50 91.5	8.84 95.0	9.18 99.0	9.52 102	9.86 106	10.20 110	10.54 113	10.88 117	11.22 121	11.56 124	11.90 128	12.24 132	12.58 135	12.92 139	13.26 143	13.60 146	13.94 150	14.28 154	14.62 157	14.96 161	15.30 165	15.64 168	15.98 172	16.32 176
3500	8.40 90.5	8.75 94.0	9.10 98.0	9.45 102	9.80 105	10.15 109	10.50 113	10.85 117	11.20 121	11.55 124	11.90 128	12.25 132	12.60 136	12.95 139	13.30 143	13.65 147	14.00 151	14.35 154	14.70 158	15.05 162	15.40 166	15.75 170	16.10 173	16.45 177	16.80 181
3600	8.64 93.0	9.00 97.0	9.36 101	9.72 105	10.08 109	10.44 112	10.80 116	11.16 120	11.52 124	11.88 128	12.24 132	12.60 136	12.96 140	13.32 143	13.68 147	14.04 151	14.40 155	14.76 159	15.12 163	15.48 167	15.84 171	16.20 174	16.56 178	16.92 182	17.28 186
3700	8.88 95.5	9.25 99.5	9.62 104	9.99 108	10.36 112	10.73 115	11.10 119	11.47 123	11.84 127	12.21 131	12.58 135	12.95 139	13.32 143	13.69 147	14.06 151	14.43 155	14.80 159	15.17 163	15.54 167	15.91 171	16.28 175	16.65 179	17.02 183	17.39 187	17.76 191
3800	9.12 98.0	9.50 102	9.88 106	10.26 110	10.64 115	11.02 119	11.40 123	11.78 127	12.16 131	12.54 135	12.92 139	13.30 143	13.68 147	14.06 151	14.44 155	14.82 160	15.20 164	15.58 168	15.96 172	16.34 176	16.72 180	17.10 184	17.48 188	17.86 192	18.24 196
3900	9.36 101	9.75 105	10.14 109	10.53 113	10.92 118	11.31 122	11.70 126	12.09 130	12.48 134	12.87 139	13.26 143	13.65 147	14.04 151	14.43 155	14.82 160	15.21 164	15.60 168	15.99 172	16.38 176	16.77 181	17.16 185	17.55 189	17.94 193	18.33 197	18.72 202
4000	9.60 103	10.00 108	10.40 112	10.80 116	11.20 121	11.60 125	12.00 129	12.40 133	12.80 138	13.20 142	13.60 146	14.00 151	14.40 155	14.80 159	15.20 164	15.60 168	16.00 172	16.40 177	16.80 181	17.20 185	17.60 189	18.00 194	18.40 198	18.80 202	19.20 207
4100	9.84 106	10.25 110	10.66 115	11.07 119	11.48 124	11.89 128	12.30 132	12.71 137	13.12 141	13.53 146	13.94 150	14.35 154	14.76 159	15.17 163	15.58 168	15.99 172	16.40 177	16.81 181	17.22 185	17.63 190	18.04 194	18.45 199	18.86 203	19.27 207	19.68 212
4200	10.08 109	10.50 113	10.92 118	11.34 122	11.76 127	12.18 131	12.60 136	13.02 140	13.44 145	13.86 149	14.28 154	14.70 158	15.12 163	15.54 167	15.96 172	16.38 176	16.80 181	17.22 185	17.64 190	18.06 194	18.48 199	18.90 203	19.32 208	19.74 212	20.16 217
4300	10.32 111	10.75 116	11.18 120	11.61 125	12.04 130	12.47 134	12.90 139	13.33 143	13.76 148	14.19 153	14.62 157	15.05 162	15.48 167	15.91 171	16.34 176	16.77 181	17.20 185	17.63 190	18.06 194	18.49 199	18.92 204	19.35 208	19.78 213	20.21 218	20.64 222
4400	10.56 114	11.00 118	11.44 123	11.88 128	12.32 133	12.76 137	13.20 142	13.64 147	14.08 152	14.52 156	14.96 161	15.40 166	15.84 171	16.28 175	16.72 180	17.16 185	17.60 189	18.04 194	18.48 199	18.92 204	19.36 208	19.80 213	20.24 218	20.68 223	21.12 227
4500	10.80 116	11.25 121	11.70 126	12.15 131	12.60 136	13.05 140	13.50 145	13.95 150	14.40 155	14.85 160	15.30 165	15.75 170	16.20 174	16.65 179	17.10 184	17.55 189	18.00 194	18.45 199	18.90 203	19.35 208	19.80 213	20.25 218	20.70 223	21.15 228	21.60 233
4600	11.04 119	11.50 124	11.96 129	12.42 134	12.88 139	13.34 144	13.80 149	14.26 153	14.72 158	15.18 163	15.64 168	16.10 173	16.56 178	17.02 183	17.48 188	17.94 193	18.40 198	18.86 203	19.32 208	19.78 213	20.24 218	20.70 223	21.16 228	21.62 233	22.08 238
4700	11.28 121	11.75 126	12.22 132	12.69 137	13.16 142	13.63 147	14.10 152	14.57 157	15.04 162	15.51 167	15.98 172	16.45 177	16.92 182	17.39 187	17.86 192	18.33 197	18.80 202	19.27 207	19.74 212	20.21 218	20.68 223	21.15 228	21.62 233	22.09 238	22.56 243
4800	11.52 124	12.00 129	12.48 134	12.96 140	13.44 145	13.92 150	14.40 155	14.88 160	15.36 165	15.84 171	16.32 176	16.80 181	17.28 186	17.76 191	18.24 196	18.72 202	19.20 207	19.68 212	20.16 217	20.64 222	21.12 227	21.60 233	22.08 238	22.56 243	23.04 248
4900	11.76 127	12.25 132	12.74 137	13.23 142	13.72 148	14.21 153	14.70 158	15.19 164	15.68 169	16.17 174	16.66 179	17.15 185	17.64 190	18.13 195	18.62 200	19.11 206	19.60 211	20.09 216	20.58 222	21.07 227	21.56 232	22.05 237	22.54 243	23.03 248	23.52 253
5000	12.00 129	12.50 135	13.00 140	13.50 145	14.00 151	14.50 156	15.00 161	15.50 167	16.00 172	16.50 178	17.00 183	17.50 188	18.00 194	18.50 199	19.00 205	19.50 210	20.00 215	20.50 221	21.00 226	21.50 231	22.00 237	22.50 242	23.00 248	23.50 253	24.00 258
5100	12.24 132	12.75 137	13.26 143	13.77 148	14.28 154	14.79 159	15.30 165	15.81 170	16.32 176	16.83 181	17.34 187	17.85 192	18.36 198	18.87 203	19.38 209	19.89 214	20.40 220	20.91 225	21.42 231	21.93 236	22.44 242	22.95 247	23.46 253	23.97 258	24.48 264
5200	12.48 134	13.00 140	13.52 146	14.04 151	14.56 157	15.08 162	15.60 168	16.12 174	16.64 179	17.16 185	17.68 190	18.20 196	18.72 202	19.24 207	19.76 213	20.28 218	20.80 224	21.32 229	21.84 235	22.36 241	22.88 246	23.40 252	23.92 257	24.44 263	24.96 269
5300	12.72 137	13.25 143	13.78 148	14.31 154	14.84 160	15.37 165	15.90 171	16.43 177	16.96 183	17.49 188	18.02 194	18.55 200	19.08 205	19.61 211	20.14 217	20.67 222	21.20 228	21.73 234	22.26 240	22.79 245	23.32 251	23.85 257	24.38 262	24.91 268	25.44 274
5400	12.96 140	13.50 145	14.04 151	14.58 157	15.12 163	15.66 169	16.20 174	16.74 180	17.28 186	17.82 192	18.36 198	18.90 203	19.44 209	19.98 215	20.52 221	21.06 227	21.60 233	22.14 238	22.68 244	23.22 250	23.76 256	24.30 262	24.84 267	25.38 273	25.92 279
5500	13.20 142	13.75 148	14.30 154	14.85 160	15.40 166	15.95 172	16.50 178	17.05 184	17.60 189	18.15 195	18.70 201	19.25 207	19.80 213	20.35 219	20.90 225	21.45 231	22.00 237	22.55 243	23.10 249	23.65 255	24.20 260	24.75 266	25.30 272	25.85 278	26.40 284
5600	13.44 145	14.00 151	14.56 157	15.12 163	15.68 169	16.24 175	16.80 181	17.36 187	17.92 193	18.48 199	19.04 205	19.60 211	20.16 217	20.72 223	21.28 229	21.84 235	22.40 241	22.96 247	23.52 253	24.08 259	24.64 265	25.20 271	25.76 277	26.32 283	26.88 289
5700	13.68 147	14.25 153	14.82 160	15.39 166	15.96 172	16.53 178	17.10 184	17.67 190	18.24 196	18.81 202	19.38 209	19.95 215	20.52 221	21.09 227	21.66 233	22.23 239	22.80 245	23.37 252	23.94 258	24.51 264	25.08 270	25.65 276	26.22 282	26.79 288	27.36 295
5800	13.92 150	14.50 156	15.08 162	15.66 169	16.24 175	16.82 181	17.40 187	17.98 194	18.56 200	19.14 206	19.72 212	20.30 219	20.88 225	21.46 231	22.04 237	22.62 243	23.20 250	23.78 256	24.36 262	24.94 268	25.52 275	26.10 281	26.68 287	27.26 293	27.84 300
5900	14.16 152	14.75 159	15.34 165	15.93 171	16.52 178	17.11 184	17.70 191	18.29 197	18.88 203	19.47 210	20.06 216	20.65 222	21.24 229	21.83 235	22.42 241	23.01 248	23.60 254	24.19 260	24.78 267	25.37 273	25.96 279	26.55 286	27.14 292	27.73 298	28.32 305
6000	14.40 155	15.00 161	15.60 168	16.20 174	16.80 181	17.40 187	18.00 194	18.60 200	19.20 207	19.80 213	20.40 220	21.00 226	21.60 233	22.20 239	22.80 245	23.40 252	24.00 258	24.60 265	25.20 271	25.80 278	26.40 284	27.00 291	27.60 297	28.20 304	28.80 310
6100	14.64 158	15.25 164	15.86 171	16.47 177	17.08 184	17.69 190	18.30 197	18.91 204	19.52 210	20.13 217	20.74 223	21.35 230	21.96 236	22.57 243	23.18 250	23.79 256	24.40 263	25.01 269	25.62 276	26.23 282	26.84 289	27.45 295	28.06 302	28.67 309	29.28 315
6200	14.88 160	15.50 167	16.12 174	16.74 180	17.36 187	17.98 194	18.60 200	19.22 207	19.84 214	20.46 220	21.08 227	21.70 234	22.32 240	22.94 247	23.56 254	24.18 260	24.80 267	25.42 274	26.04 280	26.66 287	27.28 294	27.90 300	28.52 307	29.14 314	29.76 320
6300	15.12 163	15.75 170	16.38 176	17.01 183	17.64 190	18.27 197	18.90 203	19.53 210	20.16 217	20.79 224	21.42 231	22.05 237	22.68 244	23.31 251	23.94 258	24.57 264	25.20 271	25.83 278	26.46 285	27.09 292	27.72 298	28.35 305	28.98 312	29.61 319	30.24 326
6400	15.36 165	16.00 172	16.64 179	17.28 186	17.92 193	18.56 200	19.20 207	19.84 214	20.48 220	21.12 227	21.76 234	22.40 241	23.04 248	23.68 255	24.32 262	24.96 269	25.60 276	26.24 282	26.88 289	27.52 296	28.16 303	28.80 310	29.44 317	30.08 324	30.72 331
6500	15.60 168	16.25 175	16.90 182	17.55 189	18.20 196	18.85 203	19.50 210	20.15 217	20.80 224	21.45 231	22.10 238	22.75 245	23.40 252	24.05 259	24.70 266	25.35 273	26.00 280	26.65 287	27.30 294	27.95 301	28.60 308	29.25 315	29.90 322	30.55 329	31.20 336
6600	15.84 171	16.50 178	17.16 185	17.82 192	18.48 199	19.14 206	19.80 213	20.46 220	21.12 227	21.78 234	22.44 242	23.10 249	23.76 256	24.42 263	25.08 270	25.74 277	26.40 284	27.06 291	27.72 298	28.38 305	29.04 313	29.70 320	30.36 327	31.02 334	31.68 341
6700	16.08 173	16.75 180	17.42 188	18.09 195	18.76 202	19.43 209	20.10 216	20.77 224	21.44 231	22.11 238	22.78 245	23.45 252	24.12 260	24.79 267	25.46 274	26.13 281	26.80 288	27.47 296	28.14 303	28.81 310	29.48 317	30.15 325	30.82 332	31.49 339	32.16 346
6800	16.32 176	17.00 183	17.68 190	18.36 198	19.04 205	19.72 212	20.40 220	21.08 227	21.76 234	22.44 242	23.12 249	23.80 256	24.48 264	25.16 271	25.84 278	26.52 285	27.20 293	27.88 300	28.56 307	29.24 315	29.92 322	30.60 329	31.28 337	31.96 344	32.64 351
6900	16.56 178	17.25 186	17.94 193	18.63 201	19.32 208	20.01 215	20.70 223	21.39 230	22.08 238	22.77 245	23.46 253	24.15 260	24.84 267	25.53 275	26.22 282	26.91 290	27.60 297	28.29 305	28.98 312	29.67 319	30.36 327	31.05 334	31.74 342	32.43 349	33.12 357
7000	16.80 181	17.50 188	18.20 196	18.90 203	19.60 211	20.30 219	21.00 226	21.70 234	22.40 241	23.10 249	23.80 256	24.50 264	25.20 271	25.90 279	26.60 286	27.30 294	28.00 301	28.70 309	29.40 316	30.10 324	30.80 332	31.50 339	32.20 347	32.90 354	33.60 362
7100	17.04 183	17.75 191	18.46 199	19.17 206	19.88 214	20.59 222	21.30 229	22.01 237	22.72 245	23.43 252	24.14 260	24.85 267	25.56 275	26.27 283	26.98 290	27.69 298	28.40 306	29.11 313	29.82 321	30.53 329	31.24 336	31.95 344	32.66 352	33.37 359	34.08 367
7200	17.28 186	18.00 194	18.72 202	19.44 209	20.16 217	20.88 225	21.60 233	22.32 240	23.04 248	23.76 256	24.48 264	25.20 271	25.92 279	26.64 287	27.36 295	28.08 302	28.80 310	29.52 318	30.24 326	30.96 333	31.68 341	32.40 349	33.12 357	33.84 364	34.56 372

Note: All combinations within heavy surround are within ±2% of 9 m^2

The matrixes, together with the decision tables on page 40, make it possible to trade off better solutions against inferior solutions; and we always finish with dimensions that are at least multiples of the basic module of 100 mm. In customary measurement we had no such aid at all, so that we did not know - prima facie - whether 10' 8" was a better dimension that 10' 4", or than 10' 6", or whether it was worse. In Australia, the area matrixes provided another example of advantageous marketing of preferred dimensions within a metric building world, and this intrinsic advantage was emphasized to the fullest.

3. The Role of the Contractor

The construction community has a clearcut objective to satisfy building needs in the most economical, functional, timely and aesthetic manner, but not necessarily in that order of importance. The real, ultimate end product of significance is the building - not just drawings prepared by designers, or products manufactured by producers, because on their own these mean very little. What really means something, is to facilitate the setting out and assembly processes to obtain real buildings and, particularly, dimensionally-preferred buildings. In Australia, we found that by standardizing our processes, practices and procedures in line with the change to metric measurement, we could accommodate some quite new approaches. We also realized that the support of the contractor and the construction forces was tremendously important to metrication and dimensional coordination.

A designer can only forecast a metric demand, sometimes years into the future. The real source of demand for metric and dimensionally-coordinated products is the contractor who places orders for "metric" and "modular" products for use in "metric" and "modular" buildings. If he orders metric preferred-size products in line with a national timetable for change, this reinforces and facilitates the changeover. If, on the other hand, he orders customary size products and shapes or modifies them for use in metric buildings, this not only will delay an orderly change by lowering metric demand and prolonging non-metric demand, but it will jeopardize his own advantages from metric dimensional coordination. Where the building dimensions and product sizes are related to each other, the processes of construction and assembly can be carried out in such a way that the objectives of dimensional coordination are achieved with greater economy and simplicity. The aims are to reduce waste, to simplify assembly operations, to improve accuracy and quality, and to eliminate any unnecessary and costly variety.

4. Metrication and Dimensional Coordination - The Importance of Research and Analysis

In Australia, we felt that in order to achieve a successful transition to a metric and preferred dimensional building environment, we had to go back to a fundamental analysis, starting from user needs and the purpose of buildings. I think this bears a lot of food for thought. We had to research into the design process - not only as it affected the architect as the prima donna of the design professions, but as it affected the entire building design community in its work on different facets of the building design process. For example, we all know the importance of the mechanical component, not only for its steadily increasing significance in terms of costs, but also in terms of the effect on structure and spaces. In order to have effective dimensional coordination, one has to resolve the dimensional implications flowing from structural and mechanical systems with those of the building envelope, internal subdivision, and detailing. In Australia, to provide a cumulative design requirement which could be met more easily in the marketplace, we recognized the important role of research to determine those areas where the work of the design professions could be harmonized by dimensional coordination. While we were limited by lack of leadtime, we still obtained a much greater understanding of dimensional interactions and conflicts in the building design process.

5. Metrication and the Building Materials Producer

In conjunction with metrication and dimensional coordination, we also undertook some very necessary studies of materials' production processes. In determining or suggesting preferred metric sizes, we could not afford to disrupt or dislocate, to any significant extent, the productive capacity of manufacturers, as this would have been reflected not only in higher prices for metric products, but in great malcontent with the metric change. Thus, we closely examined production and related matters, and discussed with manufacturers of all kinds various aspects of production costs, manufacturing equipment costs and useful life, adaptability, inventory control, and pricing procedures. We found, for example, a very similar result to that mentioned earlier in this meeting, namely that 90% of the standard product line frequently subsidizes the 10% of specials. In establishing preferences for product sizes, we pointed demand towards preferred alternatives, thus assisting not only the purchaser but also the producer.

In some industries, long production plant life appeared as an obstacle to a change to production in preferred metric dimensions. But after some hair-raising early estimates by industry of the cost of changing to metric production in preferred sizes, we found in many instances that the difficulties associated with the adjustment were not very great at all, particularly where metric production was linked with planned obsolescence of manufacturing equipment.

One major brick manufacturer, for example, changed his primary source of sizing of clay bricks every day. The company had changed from the use of high quality extrusion dies which needed to be replaced every three to six months (when the force of the clay being squeezed through gradually had enlarged the extrusion opening beyond acceptable tolerances), to an even higher quality extrusion die with a mild steel insert in the extrusion opening. A new insert was installed every morning after being abraded during the preceding day's production, and in that manner the manufacturer maintained extraordinary dimensional control, meeting even the most stringent standards with a dimensionally controlled end product. With only minor changes, it was possible to utilize a different insert to produce preferred size metric bricks with the existing plant at only a few days notice.

It was not that simple with all other manufacturers. Many of them were reluctant to abandon the production of customary products which had a vast historical legacy in terms of established sizes, quality control, technical data, and peripheral standards with almost an aura of their own. And it is not easy to surrender all this on the altar of metrication.

But to meet the best set of objectives for an inevitable metric building world, we had to seek out the optimum path. When I say we, I do not mean the Government of Australia; I mean the people who were associated with the Australian Metric Conversion Board, who were from all areas of the design/production/construction community, and among which the private sector dominated. These people developed consensus decisions out of a vision of and dedication to a metric building world much better than that which existed. All of them gave their efforts freely - not for selfish reasons, or glory, or medals, or other forms of recognition, but because they quickly found that the change to metrication and dimensional coordination provided a reservoir of opportunity that had hitherto been untapped.

The questions which were important were: How can we tie metrication into the replacement cycle? How can we substitute an optimum product range? How often is the manufacturing equipment replaced or modified in normal operations? How quickly and successfully can the cost of a once-only change to new and preferred sizes be recouped?

Initially, we were told that the concrete block industry could not change to metric preferred sizes, because blocks were produced in molds that had a long life, and were not very adaptable to dimensional changes. But the concrete block manufacturing industry had a target date for the planning of its most expedient replacement cycle for production equipment, because the Australian construction community had established a metric timetable, and an M-Day early on. It is interesting to note that it was this industry which became the first sector to produce and market metric products in preferred sizes. This was because some of the initial objections that only looked at metrication in terms of difficulty and cost, had not stood up and had been "blocked out."

6. <u>Cost Estimates Relating to Metrication and Dimensional Coordination</u>

One of the great lessons from Australia is that if any group wishes to raise obstacles to sensible changes, then it is easy to make some wild estimates of cost that serve no real purpose but will retard efforts within the group as well as within the sector at-large. Objections arise principally from a lack of awareness of the issues and aims in metrication. But if one wants to make "the most" of metrication (and dimensional coordination is part of the most), then everyone has to yield or give a little, in order to achieve the positive balance described earlier.

In Australia, we found that most cost estimates were pretty meaningless because a lot of the costs that were assigned to metrication would have been incurred or absorbed in the normal business cycle anyway, whether in design, or production, or construction. To concentrate on costs alone tends to close the eyes to many of the opportunities.

We did realize, however, that our standards-setting groups would incur some very significant costs for some time in changing the entire data bank of standards, codes, and other technical information from the customary measurement base to metric units. But then these groups also were going to be rewarded handsomely. With the obsolescence of traditional data, new and up-to-date information was required all round. With a properly managed program, the initial or investment costs were quickly recouped by sales. Indeed, metrication provided a very lucrative avenue for the standards-setting bodies that had to do much of the early work.

7. Metric Trial Projects

In order to make an effective transition to a metric and preferred dimensional building world, some effort has to be concentrated beyond design and production, and has to address the construction process. In Australia, the Federal and State Governments undertook trial or pilot construction projects prior to full-scale metric operation to assess whether there were any problems in metric work, and to test some of the dimensional hypotheses to see how well they would work.

In my opinion, it is a very necessary and proper function for the public sector to lead the way at an appropriate time and to become a catalyst for the community at-large. This was especially so in Australia, where it was the national objective to make the least costly and most beneficial voluntary change to a "metric" and "preferred dimensional" construction environment. And the term "voluntary" applies equally well to the public sector, because if no one volunteers, then changes simply are not made.

Some of these trial projects were simple, small buildings, costing in the order of 20 to 200 thousand U.S. dollars; others were quite major national projects, costing up to 200 million U.S. dollars. The latter were started as metric projects because it was realized that the time cycle to design and construct a 200 million U.S. dollar facility extends over so many years that it would be unwise to build in customary units, and thus create a prematurely obsolescent facility of such magnitude simply because of the strict adherence to a timetable.

Even though construction was scheduled to commence before the M-Day, the bulk of the work would take place in the metric period, and thus a deliberate decision was appropriate to make it an "early" metric project. On the credit side, a large project generates sufficient repetitive demand to encourage manufacture of metric products without penalty cost, while simultaneously providing the producer with a good insight into the issues in a metric project world.

The trial and early metric projects showed very distinctly that many of the imagined problems on the construction site simply do not occur. There is strong support for metric operations from all site labor, as soon as the simplicity of a fully decimal measurement environment with only one unit of measurement begins to be understood--and that does not take very long.

8. Opportunities vs. Problems in a Metric Building World

The most significant lesson we learned during metrication in Australia - one that I have been endeavoring to convey for the past ten months in the United States - was that if one wants to make the most of metrication, one has to pay attention to opportunities rather than to problems. There is one fundamental difference: problems come after you to give you so-called "problems;" whereas, opportunities never come after you - they have to be searched out, and willfully, diligently and methodically pursued.

Metrication can be likened to the engine in front of the train of opportunity with carriages such as dimensional coordination, review and rationalization, variety reduction, harmonization of practices, unification of building requirements, and better communication. In this train, the most significant unit is the establishment of a comprehensive system of dimensional coordination for use by and linking of all constituent parts. To be successful, such a system must spring from a concerted national exercise.

In my experience, there never has been anything quite as far reaching or quite as successful in the history of the Australian construction community as the cooperation that was obtained, firstly, in making the change to a metric building environment (the easy part) and, secondly, in providing the basis for a comprehensive and lasting system of dimensional preferences.

9. Some Issues to Avoid

In making the change to metric, there were a few problem areas in Australia where expediency or singlemindedness overruled rationale. The most notable failure in metrication occurred in the lumber industry, and it will take a second change some time in the future to correct the situation. Without wishing to be facetious, it appears that the lumber industry broke into three pieces: firstly, the softwood lumber industry, which decided to make a hard conversion (with guaranteed minimum sizes) and which abandoned nominal sizes; secondly, the hardwood lumber industry, which decided to make no real change, but which continued to describe lumber by rounded nominal metric sizes; and finally, imported lumber suppliers, which marketed a third and different set of sizes. The result for the construction community was that instead of one set of metric sizes and one set of preferences, there were three differing sets of lumber sizes and preferences. This makes it inordinately difficult for the designer to create detail designs in lumber for dimensionally-coordinated buildings. But neither designers, nor contractors, nor users, had been properly represented in the discussions and decision on lumber sizes. The design professions now are turning to alternative structural materials to preserve the dimensional relationships that become so necessary in a world of dimensionally-coordinated building.

It could have been that the rapid time cycle in Australia was too ambitious to allow for detailed debate and extensive research and analysis on all aspects of lumber sizes and properties - there was only three years from initial metric planning to the industry

M-Day. But, what is more significant in the U.S. context is that it is important to have a balanced presentation of views and concerns before binding decisions are made and implemented. Otherwise, the metric opportunity to improve the construction community will be squandered and it will continue to work very much below the optimum. Metrication provides the best possible catalyst for discussions across all parts of the industry.

CONCLUDING REMARKS

I would like to reiterate something that my friend, Chuck Mahaffey, remarked upon earlier. I believe that "pragmatism" is the most valuable asset we have in attacking the transition to the metric system, and the almost equally inevitable transition to a system of preferred dimensions and sizes. To be a metric apostle and to wish for everything in nice, neat metric values has its place, but there are many aspects in the construction community where it is unnecessary, if not counter-productive, to make a change just to arrive at nice numbers. There are quite a few areas where we need not change just for change's sake. But, in establishing a culture of preferred dimensions and sizes, and metric dimensional coordination, it becomes necessary to insist on simple numerical values.

As far as pragmatism is concerned, we have to acknowledge that <u>some dimensional coordination is better than none, and full dimensional coordination is better than some</u>.

QUESTIONS AND ANSWERS

Mr. Gerald Prange

You heard this morning--if I may serve as devil's advocate--that the two gentlemen from Europe have anti-regulatory proclivities. However, having worked in the building materials' industry, and having been involved with building codes and standards for many years, I am always a bit sceptical when I hear such a pronouncement. Subsequently, a Hans Milton may propose adoption of an SI system without modification, and we then find we are more specifically and more rigidly regulated than when operating under the old system.

Seriously, with regard to modular coordination in building design, we want to be sure today that we are not assuming that the U.S. building industry is starting at ground "zero."

In the past, many in the U.S. building industry have been "turned-off" when the subject of modular coordination was introduced because of the complexities associated with the term. It is possible that some of the difficulty in introducing modular design in Europe also has been a result of the terminology that one of the speakers this morning referred to as just "good common sense." We, in the U.S., have quite a heritage of modular coordination, or whatever you would like to call it, particularly in the light frame industry. Ray Harrell of the National Lumber and Building Material Dealer's Association, who is attending this meeting, and who is the grandfather of the LURECO system for wood frame construction, would recognize this. This system is based upon the 4-inch module and currently is practiced by many builders throughout the United States. About ten years later, that system was followed by the UNICOM system, which completely organized light frame construction as a totally modular system, again utilizing the 4-inch module.

The spacing of members in the UNICOM system coordinates with the 4 feet x 8 feet dimension for plywood, for gypsum board, and other panel products. So, we are fairly well modularly coordinated in light frame construction. I cannot speak with any degree of background regarding commercial and heavier types of construction, where the 5 foot module and other systems have been used. But, so far as light frame construction is concerned, while we do not regularly refer to it as modular coordination or modular dimensioning, most builders, most architects and planners have been designing and building on this basis for quite some time.

What many have come today to discuss and determine is: How far have we come in modular planning and design of buildings? What more should we be looking forward to in adopting--or adapting--to modular coordination, beyond the basic light frame system in use today?

The first question deals with the general attributes and benefits of modular coordination. I would like to refer to a recent project by the U.S. Department of Housing and Urban Development (HUD) called "OPERATION BREAKTHROUGH"--a great move to industrialize the entire building process for residential construction. This was a major governmental incentive, and it involved participation of a number of large industries which were new in the building business. These industries were encouraged to become builders of modular housing, (and

Governor Romney, the then Secretary of HUD was instrumental in promoting this concept) the idea being that if General Motors, American Motors, Chrysler Corporation, and Ford could produce automobiles on an assembly line, it should be possible to turn out housing in a similar manner--particularly, if modular design and component construction were employed. As you know, a good many of these people lost their financial shirts in this effort which did not produce the envisioned economics of scale.

However, a housing recession that followed the "BREAKTHROUGH" effort did not help that situation very much. But, the firms that survived and are continuing to produce housing and doing very well today, are the smaller builders--both factory-built and "stick" or site builders. They are using and traditionally have used the 4-inch design module and components of lumber, plywood, gypsum board and various types of panel products, all of which coordinate with that module. My question is: What should we be doing in the modular coordination field that we are not doing, in order to improve the industrialized home building process?

Mr. Hans J. Milton

This meeting is an exercise of consultation and communication and I hope there will be many more throughout the entire metrication process, because the designer on one hand, and the producer on the other are undoubtedly the most two significant parties in bringing about dimensional order within the construction community. And, I think they need to talk more than any other group. But, not exclusively, they must bring the other skills into the discussions as will become pretty clear as we get into more detail.

I have recently talked with one of the legal representatives of the department that conceived this marvelous idea of "OPERATION BREAKTHROUGH," and I was assured that specifications in "BREAKTHROUGH" were based upon the concept of specified functional performance, but that the geometric performance--the dimensional requirements--were left fairly open. There were only very general prescriptions as to minimum requirements in certain situations. I think the fact that the U.S. building community is already familiar with the concept of a 4-inch module, is a distinct advantage in changing to an even wider concept of dimensional preference during metrication. It seems that the customary preferences involving 4 feet, and 2 feet, 16 inches, and 4 inches have not gone far enough--they have not been extended throughout the total conceptual framework, including preferred building dimensions, recommended functional spaces compatible with modules, tolerances and limits of fit, to mention just a few. This is why, earlier I mentioned "partial applications." The real gains will come from a comprehensive and coherent approach that extends through all areas of the building community.

Mr. Prange

Mr. Milton mentioned, "Thou shall use the millimeter as the basis of preferred dimensions." This gives us a 1200 x 2400 mm panel for the standard plywood or gypsum sheet, hard converted. I think that is fine and it works well. But, I have problems in determining whether and how a 1200 x 2400 mm panel, which coordinates with the 100 mm module, is simpler than a 4 feet x 8 feet panel, which coordinates with a 4-inch module.

Mr. Milton

Prima facie, a panel size of 1200 mm x 2400 mm is not any better than a 4 feet x 8 feet size, because each measurement should be used in its respective measurement environment.

Therefore, to have the equivalent of a 4 feet x 8 feet in a metric environment would be against all basic principles; to have the equivalent of 1200 mm x 2400 mm in a customary environment would be equally difficult although slightly simpler, because in most instances it is easier to make up in size than it is to subtract. For example, you could easily use a metric concrete block, which is slightly smaller in size than the customary concrete block in a customary environment, because it is easier for us to make the joint a bit larger than it is to narrow it down to nothing. The mathematics are simpler when you use only one unit of measurement (millimeters) compared with two (feet and inches).

Mr. Prange

You mentioned, that in Australia you began--not necessarily in the order perhaps that you might have preferred--with the development of preferred sizes of building components. The question I ask is: Did this come before the effort to standardize the building module?

Mr. Milton

The module was standardized before preferred dimensions and related preferred sizes were developed. I do not think that preferred sizes of building components came entirely before we settled on preferred building dimensions. It was like having twins, not identical twins but a pair of siblings, where one is the "preferred sizes for the manufacturer," and the other one is the "preferred dimensions for the designer." However, both arrived together and are derived from a common genetic framework, and that framework is the 100 mm module and a specific selection of preferred multiples.

Mr. Prange

Returning to the facetious, in your speech you mentioned that 5 feet 8 inches (the average male height) comes to approximately 1700 millimeters, which, as you indicated, is modular with 100 mm by a factor of 17. Interestingly, in the present system, 5 feet 8 inches is 68 inches, which is modular with the 4-inch module, again with a factor of 17. So, I ask, how is the new system with two extra digits on each dimension a simpler system?

Mr. Milton

The reason why I deliberately chose 1700 mm was the fact that in the old (modular) concept 17 modules represented 5 feet 8 inches or, as you stated, 68 inches. And that appeared to be as good a multiple of 4 inches as any other. But, in metric dimensional coordination or international modular coordination, there is an additional factor, because other preferences with multipliers such as 16 or 18 have better intrinsic qualities: they allow more divisibility or easier manipulation than the multiplier 17, which is a "prime number." The multiplier in metric dimensional coordination is immediately visible and not hidden. My choice of 1700 was to illustrate a facility we have never had before. The actual measuring units (the meter or millimeter) indicate linear measurement, but the number (the numerical value) indicates the geometric properties. So much so, that on a drawing in millimeters, you can leave the "mm" off and just show numbers. But such numbers have certain qualities in terms of divisibility that become immediately apparent.

Let us take another number to get away from 17. For example, 3600 mm or 36 modules. Can anyone here tell me what 36 modules would be in customary measurement? - well, it is 12 feet. Twelve feet can be divided into twice 6 feet, three times 4 feet, four times 3 feet, etc. And, as we go on with the mental arithmetic, we are likely to overlook a few of the possible alternatives.

But when we take 3600, we can ascertain immediately that it represents: 2 x 1800, 3 x 900, 6 x 600, 9 x 400, 12 x 300, and 18 x 200--all of which are directly visible. Had we taken 3500, which is the nearest dimension to 3600, we would have had the option of splitting this up into 7 x 500 or 5 x 700, but nothing else would divide into whole multiples of 100. And, if we had taken 3700, which has a prime number as multiplier, we would have arrived at an even more inferior dimension. You know, some architects with good intentions might convert 12 feet to the metric equivalent of 3658 mm, and then round to 3700 mm. A room dimension of 3700 mm cannot be made up in distinct components without having to cut or fit.

We could just say 36 M in lieu of 3600 mm, the way the Swedes do, but then that would not allow us to use the same unit of measurement for the more detailed tolerancing, for the more detailed basic size, for the manufacturing deviations that we can tolerate, or for the positional deviations on-site, because there we need to go into millimeters. To go into anything smaller than millimeters in general building construction would be useless, because one cannot measure it. But with one measurement unit--the millimeter--we can deal with the smallest and the largest dimensions that are likely in production and construction.

Mr. Prange

Mr. Milton has mentioned a room size of 9 m^2 as a standardization for a room which might be 100 square feet (10 feet x 10 feet or 8 feet x 12-1/2 feet, or some other rectangular configuration). What we really find when we study interior room dimensions is that acoustical, appearance, fire protection, or other considerations dictate a myriad of wall thicknesses. And, try as we might to make interior room dimensions modular, the variability in thickness of wall materials tends to make it rather difficult to establish precise dimensions. Would you comment on that?

Mr. Milton

In choosing an area criterion, I had intended to illustrate the difficulties we get into in trying to convert, say, 100 square feet into a range of options stated in 4 inch multiples - such as 10 foot x 10 foot, 9 foot 8 inches x 10 foot 4 inches, 9 foot 4 inches x 10 foot 8 inches, etc., and to appreciate what trade-offs are possible.

My reason was not so much to compare metric measurement with customary measurement, because it is nearly as difficult to relate an area in square meters to two preferred dimensions as it is to relate an area in square feet to dimensions in both feet and inches. But, by having an in-between device, an area matrix as a design aid, we can get straight away to explicit preferences that will assist both the designer and the producer.

I agree that "actual room dimensions" often will not be in neat multiples of 100 mm - but the "coordinating dimensions" ought to be multiples of 100 mm.

Mr. Prange

It really interested me when you mentioned the varieties of the 2" x 4" size coming from the lumber industry. Originally, the 2 x 4 was rough sawn. It was also green or unseasoned. To make it easier to handle and more stable in use, it was subsequently kiln dried and surfaced. When you begin with the 2 x 4 rough dimensions and kiln dry it, it reduces to about 1-3/4 inches x 3-3/4 inches; then you surface it to 1-5/8 inches x 3-5/8 inches, which for many years was the standard size for the 2 x 4. Then we began to look at the functional purpose of a stud in a house, and this is the real reason for coming to this kind of explanation. We have modular spacing 16 inches or 24 inches on-center, based on the 4-inch module. What load does that 2 x 4 have to support? It was found that changing the dimensions of the stud to 1-1/2 x 3-1/2 inches readily provided adequate strength and stiffness.

So, those are the sizes that prevail today. My reason for providing this history is that we need to be pragmatic in metric conversion and in the modular coordination effort, because there are other factors to be considered, factors beyond design or dimensional simplicity. And, one of these is the engineering of the structure. That is, where you can determine the most efficient product size to support imposed loads (wind loads, snow loads, etc.), these should be the dimensions used regardless of whether the current or metric system of units prevail. And, this is not so hard to rationalize. In the wood products industry we say, "Let's standardize on the modular design of the building--the center-to-center spacing of members (joists, studs and rafters) and then, let the actual cross-sectional dimensions of the structural elements depend upon the engineering requirement of the structure."

Mr. Milton

In metrication, nothing should be sacrosanct, and I am very pleased to hear your remarks about the 2 x 4. Some additional remarks can be added. In taking into account what the sizes might be, we are engaging in a research exercise. This research exercise is just as important to industry as it is to the designer and the community at-large.

Fortunately, we have adequate lead time to do some research. There is no one who will need metric lumber sizes for at least the next two years, or the next three years, or maybe even the next five years, apart from our friends in Canada. The U.S. has ample lead time to make sure that all the factors that lead to sizes are examined. You need to investigate considerations such as spacing, strength grades, effective face width (to make it possible to either fix with nails, screws, or adhesives), bending and warping, the composite structure (where the outside panel acts as a stress skin upon the actual framing member), the amount of thermal insulation you can accommodate within a laminated panel, acoustic properties and fire resistance properties - and then, there will be a whole series of trade-offs to make. Once the issues have been established, you can discard those that are of lesser significance, and concentrate on those that are of greater significance, with the ultimate goal to get better results for all. Nobody involved in metrication wants to dislocate industry. I do not think that has been anyone's intention in Australia, in Britain, or anywhere else. But, by the same token, the greater good of all parties should be advanced.

It may very well be that the ideal replacement of the 2 x 4 looks nothing like it. One ideal replacement would be an "I" section similar to that in steel. If we could cut such a shape in some fashion, it could be the ideal replacement for a 2 x 4; it would be just as strong but more economical. Maybe, one day when we have laser beams that can cut a section, such as an "I" section or any other shape, this will lead to some completely new approaches. But, this is unreal with present technology so we have to think in terms of rectangular lumber sizes.

The important thing is for the manufacturing sector, the design sector and the research capability in the country to get together and talk about the issues conjointly, rather than separately. And, that does not just apply to lumber sizes, it applies to pretty much everything. There are some obvious areas; for example, the 4 x 8 panel. There is not really any other preferred metric size than the very obvious size which has already been identified in discussion in some of the committees. No matter how hard we strain to invent some new alternative, we are bound to come back to the obvious size (1200 x 2400 mm)

But there are other areas where the ideal size is not obvious, areas where conversion is going to be much more difficult, and where the opimum solutions still need to be found.

These are some of the answers to your questions.

Mr. Prange

Professor Wandmacher has a question.

Professor Neil Wandmacher

I think you led very well into a key point on which perhaps Mr. Bergvall would want to talk further. This morning he mentioned the issue of applying the module to center-to-center dimensions versus face-to-face dimensions. What has just been said leads very naturally into this. It would be very interesting to me, from an engineering point of view, to have Mr. Bergvall talk a little bit further about the Swedish and international experience in using the center-to-center rather than the face-to-face dimensioning.

Mr. Lennart Bergvall

What I said was that the general practice in most countries today is to apply multi-modules as a guidance for the load-bearing structure, between center lines. In early modular coordination, Albert Bemis started from the face-to-face application of the basic module. Nowadays, when the multimodule, or basic module, is used to determine the location of the load-bearing structure, it is very natural to do so from center lines. Some countries maintain that they lean toward other alternatives too; but I will not go into those complications.

However, if one employs a load-bearing system based on a 3 M multimodule, the most interesting feature of that is that the sizes of rooms are more likely not to be multiples of 3 M than to be so, because the thickness of wall constructions has to be deducted. So, it is quite natural that one will need to arrange components for internal equipment, partitions, etc., in such a way that a popular dimension is reached. And now we have found that one practical way to solve that problem, if it is an appropriate building type, is to operate a 3 M, 6 M, or even 12 M multimodular grid for the positioning of the load-bearing system between center lines. Then one can have, if required, a basic modular grid for the positioning of all partitions and internal equipment, and that could be dislocated or displaced from the basic modular grid so as to achieve a situation where one has the advantage of both--a very rigid multimodular standardization of the load-bearing structure, but all the freedom of design that is needed in the internal layout of the building.

Some people try to achieve the same type of 3 M multimodular standardization to the structure, as well as to the internal design of the building. Thereby, they buy themselves a high degree of reduction of variance at the price of freedom in design; and I am not the one to say which is right or wrong. But, you can imagine from my remarks which I believe to be right.

Question from the Floor

I am aware that 100 mm and 10 cm are the same. In their speeches, the Swedish experts referred to 10 cm. It just seems to me that when you use millimeters, aren't you carrying the connotation of a larger degree of accuracy than can be obtained in construction? I can understand millimeters for mechanical items, tools, or screws and nails; but in talking about dimensions in construction, isn't the millimeter an awfully small unit?

Mr. Milton

Mr. Bergvall, maybe you would like to give an answer. I can provide one answer to that.

Mr. Bergvall

Well, I could also give an answer.

Mr. Milton

There was much debate in all of the countries that have preceded the United States in metrication on the "centimeter" versus "millimeter" argument; that one is almost as bad as the argument on the spelling of meter in the first place. I don't wish to get into that because we could be here tomorrow.

Question from the Floor

How do you spell it?

Mr. Milton

The most sensible spelling is probably the Russian spelling. They leave the "e" out and spell it m--e--t--r, and, therefore, they do not get into either controversy. It also is more efficient, because it saves you 20 percent in terms of the word length.

Let me return to the question. One of the reasons for the choice of the "millimeter," apart from the fact that it is the internationally preferred unit, was that it saves time and is more efficient in terms of the number of spaces it takes to show construction dimensions, as all measurement is in whole numbers. With the millimeter we do not need decimal points, because we do not have to have decimal fractions, which would be inevitable with centimeters, for example, in the expression of panel thickness. Consequently, cross-walls expressed in centimeters would have to have fractional dimensions. Even if they were rounded to the nearest 5 mm, the dimensions still would show a decimal fraction. From our experience and tests, people cannot add a number plus a fraction as easily in their minds as they can add a whole number. For example, you can add 128 and 265 more easily than 12.8 and 26.5.

The second reason is that, in order to improve productivity, we are bound to make greater use of computers; and computers do not like decimal points. The decimal point represents an additional space and a nuisance which need not be carried. So, in terms of the logistics of showing measurements, it is better to work in millimeters.

A major spin-off occurs in documentation. With five digits one can show any length up to 328 feet, and this dimension encompasses most of the general building dimensions. If all dimensions are in millimeters, the designation of the measurement unit may be omitted from the drawing, and one only has to deal with numbers. Three numbers suffice up to about 3 feet 3-1/3 inches; four numbers suffice up to 32 feet 8 inches; and, five numbers suffice up to 328 feet; just to put it into a customary context. This simplifies all processes of addition, subtraction, division and multiplication.

Finally, there is no risk of confusion, as is bound to arise with both centimeters and millimeters, and confusion should be avoided in the change to SI.

Question from the Floor

I was considering mainly the worker, not the engineer who has a computer. I am thinking of the laborer out on the job who is very familiar with inches and fractions--9-1/2", 9-3/4", etc.--so the fractions do not bother him in the metric system where you could have 9-1/2 cm, 10-1/2 cm, etc. There is no problem there because he is thinking in inches, and he could just make a centimeter analogous to an inch. That would not be foreign to the worker. I am more concerned about the worker who does not have the education; the educated people--the engineers and architects--can adjust to anything because supposedly they do have the education, they have the computers. But that man out there on the job--he is the one who I am worried about.

Mr. Milton

Well, let me tell you, we also talked an awful lot about workers in Australia, because we felt that the actual on-site staff was going to be a great problem. But these workers will take to any decimal measure, because a decimal system is simpler for a start. It does not matter whether the measuring tape is in millimeters; provided, you have it clearly identified, that is as simple as working in centimeters, or in meters, or in any other decimal unit. I believe that one has to be consistent when trying to attempt a solution, in order to satisfy the largest number of parties. In only one area would I be willing to advocate use of the centimeter; namely, the lumber industry. And then to disguise millimeters, because then you get some nice round numbers; 4 x 9 (cm) would be 40 x 90 (mm), rather than a 38 x 89 which is the direct conversion of a section or the 2 x 4.

Audience Interjection

Just great!

Mr. Prange

Forty by ninety (40 x 90) would be worse!

David Brackett

I do not think you have ever watched a drywall mechanical hang board with his partner, where he measured 9 foot 6 inches and a strong "1/8" or a short "3/16." It will drive you crazy. I have some questions for Mr. Milton.

I presume that in Australia, the hard conversion to the 1200 x 2400 mm panel size has transpired? Are you actually in production.

Mr. Milton

Both answers are yes.

Mr. Brackett

I am faced with a dilemna from the sheet good manufacturer's--panel manufacturer's point of view. Their immediate reaction is that going from 4 x 8 to 1200 x 2400 represents a loss of 1.5 percent of total production. And, we in the gypsum industry, are looking at production figures between 12 and 15 billion square feet per year. That amounts to a lot of money.

One more step--we are also faced with retrofitting, remodeling, whatever word you care to use, of as many as 50 million housing units. Should we go to the smaller size--the 1200 x 2400? Is this not going to create a very large economic problem in making these existing housing units more modern, up-to-date, conform with energy standards or whatever we happen to deal with, rather than considering sizes just on the basis of new construction.

Mr. Milton

Maybe Australia is of a different order of size - we do not even have five million dwellings in the country.

In Australia, we analyzed this issue very carefully and found that retrofit was no problem. In fact, the way cladding materials or sheeting materials have been used traditionally, is that they have been cut up and shaped in order to suit the geometry of internal spaces: over doors, under windows, around ducts and vents. With doors being placed somewhat arbitrarily wherever it suited the design, rather than in relation to minimizing the number of sheets that had to be cut, we get a lot of odd spaces. We believe that a new sheet size in preferred metric dimensions represents no problem. In fact, we found that much of our housing was not built with 8 feet ceiling heights, but with 8 feet and 1-1/2 inches. This was because you just cannot accommodate an 8 feet sheet or panel in an 8 feet ceiling height, so you have to cut off a little. You will find that most of your partitions designed for 8 feet ceiling heights will have a liberal part sliced off at the top, at the bottom, or both, in order to fit in, and to allow for adjustment.

But, that is only one-half of an answer, because the question is a good one. I believe that in going to a preferred dimensional environment, one must do one thing and that is "not to look over the shoulder." The moment we look over our shoulder, we see so many ghosts, we see so many reasons not to change, and not to modify anything, that we freeze with concern and do not obtain the benefits of anything that is beneficial. I do not know of any composite solution where you can have the best of two worlds. If we had this situation, it would be marvelous because then we would have had an identical 4-inch and 100 millimeter module in the past. But, we have not. So, in order to get maximum benefits all around, we ought to turn our back on the past and look into the future, and that means different sheet sizes.

In Australia, manufacturers also said, "We are going to lose 1-1/2 percent of total production." And we replied, "How much are you going to lose in sales?" They said, "Well, that's a different question." They did not compensate in their sales for this reduction in size. But in effect, there was no direct increase in the cost of housing as a result. Because, for better or for worse, through metrication our dimensions shrank ever so slightly. Ceiling heights reduced down from 8 feet, which is 2438 mm, to 2400 mm. In the total building context, this did not make very much of a difference. In fact, we managed to increase our brick size modularly so that we could accommodate the floor to ceiling height with one less course of bricks. That was a distinct advantage. But in terms of energy conservation, in terms of heating or cooling a space, we had unwittingly gained an advantage, because in a smaller space it is easier and costs less to get the desired climate by heating or cooling.

I cannot give you a better answer. I think that there are some instances where, in an historical context, the present solutions are good; but, in a future context, they are not so good. Each case requires a value judgment. If manufacturers want to continue to produce for a replacement market, this may very well be a lucrative area for production. But, if one wants to have genuine metric design, and genuine metric buildings, then the soft conversion of existing products would be a distinct handicap.

Mr. Bergvall

Industry must base its decisions on hard, matter-of-fact calculations; and so far I agree with the previous speaker. But, there is, according to my experience, a tendency within industry to over-estimate the importance of those factors in a calculation which are easily quantifiable, although those, which are not possible to quantify might very well be the decisive ones. To attach too great importance to such marginal losses of production capacity as the previous speaker mentioned just because they are so easy to calculate can be very misleading indeed.

As for metric lumber sizes, I must admit that although we in Sweden have lived happily with metrics for about one hundred years, we have only recently begun to use lumber sizes in millimeters. Until then, we successfully used the inch system of lumber sizes, simply because all of our large export buyers wanted sizes in inches. And, in a way, this was very practical; the 2 x 4, for instance, was used rather as a name - or a "number," if you like - for a certain piece of lumber, and not as an exact size.

But one should talk about marginal losses and gains by metrication; notice that the metric size of a 2 x 4 is 50 x 100 mm, against the existing 50.8 x 101.6 mm. And, the slightly smaller size will beyond doubt serve the same purpose, because we have found in Sweden that with about the same climate and snowloads as in the United States, we can use 2 x 4 studs 600 mm (24 inches) apart instead of your traditional 400 mm (16 inches). That way, you can really save lumber, provided your code system can cope with it.

Mr. Prange

We certainly are seeing a change in some of our light frame building habits as a result of the energy conservation movement, and we are now building with 2 x 6 studs.

Mr. Bradley Field

The emphasis seems to be on statistics so let me continue a little bit.

First, with respect to the gentleman's question with regard to the sizing of the panels, I could not find the statistics for Great Britain, Canada, or Australia, but we are talking in the trillions and trillions of square footage of existing space in the U.S. Much of this, which has laid to waste by the degradation of the inner cities, is going to be re-served in the future, and I do not see how we are going to be able to live with the 1200 x 2400 mm module unless they come with panel stretchers.

Keeping in mind the relativity of statistics, the gross national product for the U.S. is nearly 5-1/2 times that of Canada, Great Britain and Australia added together; and that applies to almost all the other statistics that you deal with, whether it is roadways, population, imports, exports, density or anything else. I would like to know, in some kind of a Syndney Opera House fashion, what kind of cost we are imposing on the U.S. for metric conversion.

Mr. Milton

This seems like a good question, but I cannot give you an equally good answer. All I can say to you is that your opportunity is also at least 5-1/2 times as large.

But let me be a little more serious because I have had to field these questions not only here, but in Australia, in a number of other countries where I have been a consultant, and more recently in Canada. As I see it, the greatest single cost in metrication is not necessarily a material cost or a conversion cost, but it's a "people cost." After all, at the very core of all of this activity we need people to think up these changes, coordinate them, manage them, and implement them. The greatest costs, in my view, are the costs of ignorance, which is a nasty word; the costs of lack of knowledge - of darting into metrication or taking a stand against metrication without a full knowledge of the facts; and the costs of unwillingness to learn. I think these factors combine to a much greater cost than any real costs of the change.

You could ask the same question of your automotive industry. How much does it cost to change the models every couple of years?

Mr. Field

Now wait a minute here. An automobile, I think most of us realize, wears out by the 36th payment. They have a built-in replacement market. When one takes a house or a building we may say that it has a 20 year life for the purpose of the tax books. If we take a look at the age of most of the buildings in the U.S., it is much greater than that--the built environment has a half life of 50 years.

Mr. Milton

I do not dispute any of these statistics, but they will not be any different for metric buildings. Buildings will have the same life, and possibly a longer life, if what we are talking about today is brought about. By standardizing the geometry, we get an opportunity to standardize products, and through standardization, through elimination of some of the unnecessary variety, we can obtain greater quality. And greater quality, ultimately, will be reflected in the economic life of the end product.

I simply cannot give you an easy answer on the matter of metrication cost. I have heard estimates by many people who are not qualified to make estimates, and I can tell you that, in every instance in Australia, where we made cost estimates, we were wrong. I made a cost estimate as to what it would cost my organization [the largest single employer in the construction community with 10 percent of total construction in Australia] to change, and I was wrong; my estimate was way out.

The actual cost was much less than I could have estimated. Now, I am an optimist, because I believe that optimists are the only people who contribute something in the long run; just as pessimists contribute very little if anything at all. But, I was even wrong on my second estimate. After I revised the first estimate, I had to revise the second estimate because it was too high. And, when we finally came to the stage where I felt that metrication could live on its own because we had done enough, I found it very difficult to persuade the organization to abondon the Metric Office. I had to find a new job to kill off the office, because we had so much money left over out of the second, reduced estimate that people wanted to use it to sit around and talk about metric long after it was topical. This happened in about every area. It happened in manufacture, in government departments, in construction agencies, in design offices, and in contractor's offices.

Initially, because we did not have a good feeling for the issues in metrication, we exaggerated two things; firstly, the time it would take to do something; and secondly, the cost it would take to accomplish it. It was not deliberate, but we always over-estimated. In the end, we gave up making cost estimates as a meaningless job, because it does not help you to convert more effectively if you start making cost estimates. Even if the cost estimate is ten times as high as it should be, you do not convert more effectively. Maybe one converts more effectively if the cost estimate is one-tenth; then you really know what your budget is.

Mr. Field

Yes, but isn't the question whether you "selectively convert" rather than "totally convert"? If you come up with figures that show probably in the neighborhood of what it's going to be?

Mr. Milton

A selective conversion was advocated by some people. I believe that a selective conversion--living with two systems--would cost you much more in the long run than using the metric opportunity once, and using it well. And, I think my friends from Sweden would agree.

Mr. Bergvall

Well, it can be very misleading, indeed, to give the correct answer to the wrong question. Did anyone believe that the metric decimal system as such would be superior on all points over the foot/inch system? But this is not the point. The point is that in this age of internationalization the metric system will put you into line with the rest of the world. Unless you believe that you are so great a country that you can ignore the rest of the world - developed and developing countries alike. And, in such a case, there are other great nations who would not! We live in an age, which could best be described by quoting an American, Wendall Wilkie, who already in the 40's had the foresight to declare: "One world or none!"

Mr. Prange

I would like to go back to Clark Tufts for a moment. Clark is a practicing architect and I would like to ask, "Where are your major problems in applying dimensional coordination?"

Mr. Clark Tufts

I believe our major problem will be with the building codes and regulations. Many dimensions such as anthropometric data find their way into the code without a logical explanation and become fixed thereafter. The code, for instance, requires a hospital patient room to have a minimum ceiling height of 8 feet 6 inches, while other locations in the hospital range from 8 feet 0 inches to 10 feet 0 inches or more in say kitchens, laundries or boiler rooms. Although we have used the 4-inch module for determining building vertical dimensions for some time - due probably to the "3-courses in 8 inches" for masonry unit coursing - our use of the module, and the availability of materials, does not change the code requirements. In my office, doors are 2 feet 8 inches, 3 feet 0 inches, 3 feet 4 inches, or 4 feet 0 inches wide based on a 4 foot module - but the codes still are in terms of 22 inch units of exit width, and nobody in my generation knows why.

As we have discussed so often, the opportunity in changing all of the customary dimensions to metric will be of greatest value if we ask each time a conversion is made, "why" the dimension was in the code in the first place. If we find that a dimension is necessary, we should then ask what the dimension should be - not just what it should be "rounded" to to make a nice easy number for arithmetic purposes.

In the long run, in a free society, demand creates the product - although we speak of the standard 4 feet x 8 feet material today - I can get drywall in 8 feet, 10 feet, and 12 feet lengths, and in some cases 5 feet widths. Dimensional coordination must satisfy real problems of environmental conditions if it is to succeed, for it is the user/client who establishes the ultimate demand. I for one do not believe he will accept 2400 mm as the one and only ceiling height everywhere for all buildings - no matter how cheap it would be to manufacture and stock one size of material. My prediction is that he will cut and fit and waste material. True dimensional coordination will take the "cut and fit" into account and minimize the "waste."

Question from the Floor

My question was fairly verbalized by someone else, but just to go a little further, I wish to address Mr. Milton. You mentioned that there was no increase in housing costs in Australia as a result of conversion. It interests me to find that out, and I imagine you are talking about the transitional period between the use of the English system and metric conversion. How can there not be an increase when you have firstly, the tooling up cost, and secondly, the dual inventory problem? Or, is there no dual inventory problem, because in seeing that metrication is coming, is there a lack or slowness in production to compensate for the change? Is there any problem with that dual inventory?

Mr. Milton

We did not find the dual inventory situation to be a real problem, because when you look at the building products that are being used in construction, you can classify a lot of them into dimensionally critical and non-dimensional or non-significant products. For instance, take concrete--with a change of reinforcement spacing you can utilize metric reinforcement in lieu of traditional reinforcement. And, you can cast your concrete into any particular geometric configuration.

But there were certain considerations in relation to dual inventory. For instance, if you are halfway through the construction of a 10-story building, and your reinforcement supply gives out, you have to accommodate this. Either you have to pre-order and stock, which means dual inventory, or else you have to have a second schedule on hand to utilize the new metric preferred reinforcing bar sizes. There is a third option - different design. In this particular instance, the customary sizes and the preferred metric sizes are derived from different considerations--one from an arithmetic series and the other from a geometric series. There are certain points where the sizes tend to coincide. So, the wise designer will operate preferably near these points of coincidence.

This situation will apply in many areas. We will get it in lumber sizes, where there are certain to be points of coincidence, if there is a change to a new metric range of lumber sizes. And, if you work within these points of coincidence during the transitional period, you minimize the dual inventory problem.

Secondly, it has been said that metrication involves tooling-up costs and educational costs. These costs were recovered very quickly in terms of simplified and speedier operations. In Australia, we had a stand-off on metrication - manufacturers and distributors in general did not raise their prices as a direct result of changing to metric quantities or metric sizes. That helped. But, in the housing community we had a high inflation rate at the same time. That was not an inflation in real building cost, but a demand-induced inflation where prices in the existing (pre-owned) housing market accelerated so rapidly (and this is the largest portion of all housing, because it accounts for 98% of all housing stock in any one year) that it had a slip-stream effect. Builders would just say, "I'm not going to be stupid and build a house for $50,000 if an old house next door sells for $75,000." That is something that has got nothing to do with metrication. But we were very careful to keep such factors apart.

In Australia, we were somewhat more fortunate than you might be, because, as part of our design process, we have an activity called quantity surveying, which is really cost estimating in the design environment. It is paid for by the client and is associated with the architect or designer. In essence, it involves a series of cost estimates--preliminary estimates, and then subsequent estimates, against which the bid and the total building cost will be evaluated. In the U.S., cost estimating is located in the contractors' offices; we have cost estimating in the design offices as well. Therefore, we had a very good idea as to what costs we could tolerate vis-a-vis the costs that might arise in the market, and we deliberately made no allowance for increased cost due to metrication.

The Royal Australian Institute of Architects tried at one stage to obtain an extra one percent in fees charged by the architectural profession on early metric design. This proposal was very quickly rebuffed, because it had been decided nationally that costs should be absorbed where they fall. That worked well, because metrication represented a sacrifice where nobody could say, "Well, you do not have to sacrifice anything, but I have to." Everybody had to sacrifice something. And, in order to recover this sacrifice, people were spending much more time wondering about where they might pick up the benefits of metrication, rather than worrying about costs.

You all know that in order to benefit from opportunities, you have to go after them. If we get bogged down with costs and problems, we will miss out on the opportunities, because we will not have time to even think about them.

This is my message to the United States. That is a message that everyone at this meeting can take away from here. You will need to be committed. To be a pessimist on metrication and dimensional coordination will not help anybody, least of all yourself.

Question from the Floor

Following that line of thought, you say that some of the costs involved in metrication are basically related to the designers' efficiency or talent. And in your example you plainly dealt with heavier construction and multi-family construction. Did you find any differential between the costs incurred, or a greater increase of cost incurred in heavier construction, as opposed to "stick building"--that is, single-family building? Because, as you know, that is not very often involved with the architect. It is more of a father-son type of activity, very archaic if you will. Was there any difference in the amount of cost incurred?

Mr. Milton

In large projects, such as structural engineering projects or other engineered projects one tends to lose cost differentials more easily, because, for a start, the materials alternatives are so much fewer. If you build a television mast, or a bridge, or a dam, the material alternatives are very much fewer than those encountered in a building project. Therefore, the costs can be identified more clearly and controlled more easily. The project magnitudes are often so large that they can generate their own demand.

I must say in relation to single-family housing, that we did not find significant cost increases directly attributable to the metric changeover program. But, in Australia, we lived in a climate of high inflation. The kind of inflation that the U.S. building community has had in recent times. If we go back a few years and find that the building cost index did go up by 10% in 1972 - 1973, (or whatever it was) and during the metric period it did go up by 12 percent, the question is, "Is that 2% difference a direct result of metrication or is it a result of other natural factors?" I believe 10% is too much; inflation should be no more than the general increase in the cose of living index. But, in the construction industry, it has been much more, here and everywhere else.

Mr. Prange

We have heard a number of terms today: modular coordination or modular dimensions; standardization; metric conversion; the cost of metric conversion; and, we are going to have another one--cost savings in construction. I think it would be very nice and would be a great motivating force if we could combine all of these things together and say: When we convert to the SI system, we are going to achieve modular coordination, standardization and metric convervsion; and we are going to have a minimal cost of conversion; and we are going to provide for cost savings in construction. Some of the points that are being made indicate that these factors are not one and the same thing. That, first of all, we do have a high *degree of modular coordination in the system we work in today. Secondly, we have a very extensive building standardization program going on under the present system just as, hopefully, we will under the metric system. On the cost of conversion, it is one of those "anybody's guesses." As I mentioned, we made a major change in lumber standards about 8 to 10 years ago. We reduced softwood lumber sizes by 1/8 inch in thickness, and by up to 1/4 inch in width. That is a substantial "hard conversion" kind of change. It cost us a lot of money to pursue that kind of change legally, and to attend hearings throughout that period. Once the change was made and implemented in 1970, we had no problems that I could detect; and I was kind of in the middle watching both sides of the operation, at the lumber dealer level and at the building industry level. We still are using the same modular designs, still the same 4-inch module, still the same spacing and so on. And, the leveling influence of it all is still the same 4 feet x 8 feet gypsum board, or particle board, or plywood panel. For dynamic cost saving in construction, whether we are talking about modular coordination or metric conversion, here again, it is possible to build in a cost saving manner by eliminating redundant pieces in either direction. One can build a beautiful, modularly-coordinated structure and be just as wasteful as ever in the placement of wood or steel framing. So, we cannot tie all of these issues together. It would be great if we could. I think it would be the greatest incentive that the construction industry could have to say: "Let's put our shoulder to the wheel and go metric."*

I do not believe that in the construction industry we are encountering the kind of dogmatic "let's-not-do-this-thing or let's-not-go-metric attitude," just because of some resistance to change. As a matter of fact, I have found in the Sector Committee, and in Clark Tufts' Construction Industries Coordinating Committee that there is a general desire to plan, because everybody feels that someday somebody is going to ring the bell at the government level. Then we are going to be stuck if we do not have a plan that has most of the big bugs worked out of it.

I am enheartened to realize that most of the people who we work with in the construction industry are positive in their attitude toward metric conversion. But, they are very pragmatic, and they want to know what they are going to gain and what they are going to lose. And, when Dave Brackett says he is going to lose 1.5 percent of billions of feet of gypsum board, it does not do much good to talk to him about modular coordination because his product is the most coordinated that we have. It is the backbone of our entire light construction industry.

<u>Mr. Bernard Frishman</u>

But, he is going to charge the same price for the smaller board as he is for the bigger board, so what difference does it make? Everything I have heard here seems to be somewhat on the negative side. Number one, the way I look at it, we are going to have these changes come about and, therefore, I think we should take a positive look at all of the issues. Saying how much it is going to cost us and all that, is immaterial. What we should do, as a group, is to go ahead with our plans and not try to fight the issue. Because right now the automobile industry is converting, Sears' is going into the sizing of all its clothing by 1978, or 1979, and if we do not turn around and watch ourselves, we are going to be the only industry left out, and then we will be really trying to catch up. My attitude is: Let's go ahead with whatever we have to do, and let us do it with a positive point of view. If we want to find holes in metrication, we can sit here all day long and find them. I think we have a good committee, and I think we should go ahead in a positive manner.

Professor Wandmacher

Just one quick observation, Mr. Chairman. I realize our meeting today has been about dimensional coordination and I think it has been a very productive meeting. Inevitably, this leads to a discussion of, "Why go metric," and even more so, "Why go SI?" I hope that before we leave the room, and particularly for those people who have not been into this before, we think not only of the structural kinds of considerations, and the linear dimensional kinds of considerations that we have been talking about, but the fact that we are talking about SI--a totally new, modernized metric system--which has very important relationships to the mechanical and electrical aspects of the building and construction industry. There is a real pay-off in the energy area, in dealing with coherent units, such as joules and watts. The mechanical part of buildings should not be overlooked as a part of construction; sometimes it is the biggest money part of it. There are many great benefits to be obtained in that part of the system of units--and SI is a new system--not just a changeover to a different kind of linear dimension.

Mr. Prange

That is a very fine contribution. We have been talking structural all afternoon and we have not been talking about mechanical and electrical. Mr. Bergvall, would you please provide us with some concluding remarks?

Mr. Bergvall

We have tried very hard in the international work on modular coordination to avoid complicated terminology, etc.; but sometimes that cannot be avoided in international standardization.

In his speech, Mr. Orlando kindly referred to me as the inventor of the ISO scheme of levels. As a matter of fact, many people have had similar thoughts--only mine happened to be passed by ISO. And this was very much so because of the valuable support from Charles Mahaffey, who from his very first appearance in ISO-TD3 (Technical Division 3: Building), strongly pleaded for some kind of hierarchic order in ISO standards.

You have no opportunity to see how Charles Mahaffey represents the United States and therefore, I am glad to be able to bear witness to it. He does not take the floor unnecessarily, but when he does, what he says is very well thought out and to the point, and this has made him respected both in ISO and in ECE work. And, in those cases where I have acted as chairman, I have been very grateful for his interventions, which generally offer a reasonable and practical compromise. I think, everyone finds it very satisfying that the U.S. is thus far so well represented at our meetings.

Mr. Prange

Thank you very much, Mr. Bergvall. Thank you ladies and gentlemen for coming to this meeting and participating in this discussion on dimensional coordination and metric conversion. I hope that I did not give anyone the impression that I am negative on either of those two subjects. I think our role in the wood products industry in relation to metrication will deny this.

Thanks especially to all speakers.

Before closing, I would like to recognize Dr. Malcolm O'Hagan, the President of the American National Metric Council, who has joined us at the end of the meeting.

LETTER OF INVITATION

Committee Correspondence

Address Reply To:

American National Metric Council

1625 Massachusetts Avenue, NW, Washington, D.C. 20036 (202) 232-4545

May 17, 1977

To: Chairmen of Sector Committees, Construction Industries Coordinating Committee

A joint meeting of the Design Sector and the Construction Products Sector is being held at 10:00 a.m., June 6, 1977. The meeting will be in the Board of Directors' Room at the headquarters of the American Institute of Architects, 1735 New York Avenue, N.W., Washington, D. C. Your attendance and participation is urgently invited.

The purpose of this joint meeting is to hear and participate in a discussion on dimensional coordination with foremost authorities on the subject. Mr. Henning Orlando of the Swedish Building Standards Institute, and Mr. Lennart Bergvall, a Swedish industrial executive and former President of the International Modular Group, have agreed to meet with us and to present their views on dimensional coordination as a design and manufacturing tool. Prior to our meeting, they will be participating in a meeting of Subcommittee 1 - Technical Committee 59 (Building Construction/ Dimensional Coordination) of the International Organization for Standardization held in Toronto, Canada. We are indeed fortunate that they have agreed to come to Washington, D. C. for this meeting while on our continent.

It is widely held that, of the opportunities to be achieved by the construction industry's conversion to the metric system, the greatest benefit will come through the development and implementation of the practice of dimensional coordination. It occurs to us that the Design Sector and Construction Products Sector will have a commanding role in the leadership and planning for dimensional coordination in the American building community. This could be the most important and informative meeting held to date with respect to benefiting from the metric conversion process.

Sincerely,

ANNA M. HALPIN, FAIA GERALD F. PRANGE

PROGRAM

JOINT CONFERENCE

DESIGN SECTOR AND CONSTRUCTION PRODUCTS SECTOR
CONSTRUCTION INDUSTRIES COORDINATING COMMITTEE
AMERICAN NATIONAL METRIC COUNCIL

HEADQUARTERS
AMERICAN INSTITUTE OF ARCHITECTS

Monday, June 6, 1977
Washington, D.C.

10:00 a.m.	Welcome:	Gerald F. Prange Vice President, National Forest Products Association Chairman, Construction Products Sector, American National Metric Council
	Introductions:	Charles T. Mahaffey Senior Building Standards Specialist Center for Building Technology National Bureau of Standards
	Presentation:	"DIMENSIONAL COORDINATION - AN INDUSTRIAL MANAGEMENT TOOL" Lennart Bergvall Chairman of Subcommittee on Dimensional Coordination International Organization for Standardization Former President (1960 - 1973) International Modular Group
	Coffee	
	Presentation:	"BUILDING STANDARDS DEVELOPMENT IN SWEDEN AND IN THE METRIC BUILDING WORLD" Henning Orlando Managing Director, Swedish Building Standards Institute
Noon	Lunch	
	Presentation:	"METRICATION - THE OPPORTUNITY FOR AN INDUSTRY-WIDE SYSTEM OF DIMENSIONAL COORDINATION: PRECEDENTS AND ISSUES" Hans J. Milton Technical Consultant to Center for Building Technology National Bureau of Standards Assistant Secretary for Housing Research Australian Government Service
	Questions, Answers, and Discussion	
4:00 p.m.	Adjournment	

ATTENDEES

JOINT CONFERENCE
of the

DESIGN SECTOR AND CONSTRUCTION PRODUCTS SECTOR
CONSTRUCTION INDUSTRIES COORDINATING COMMITTEE
AMERICAN NATIONAL METRIC COUNCIL

June 6, 1977
American Institute of Architects
Washington, D.C.

Fred Armstrong
Associated General Contractors

Romeo Aybar, AIA
Member, Dimensional Coordination-
Metric Conversion Task Force

George Becker
Armstrong Cork Company

Lennart Bergvall [Speaker]
Chairman, Subcommittee on Dimensional
Coordination, Technical Committee 59,
International Organization for
Standardization

Sandra A. Berry
Center for Building Technology
National Bureau of Standards

David E. Brackett
Gypsum Association

David Brown
Concrete Reinforcing Steel Institute

Ward V. Buzzell
Center for Building Technology
National Bureau of Standards

Beatriz de W. Coffin
American Institute of Landscape Architects

Charles Danner
American National Metric Council

R.J. Denny
Air Conditioning and Refrigeration
Institute

R.S. Dreyer, AIA
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Arthur F. Duncan
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Programs and Resources

Bradley G. Field, AIA
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Donna Fiscus
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Fred F. Foote
American Society of Safety Engineers

Bernard L. Frishman, AIA
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American National Metric Council

James G. Gross
Center for Building Technology
National Bureau of Standards

Raymon H. Harrell
National Lumber and Building Material
Dealers' Association

F.E. Hein
U.S. Navy
Naval Facilities Engineering Command

Lawrence Hill
American Society of Landscape Architects

Thomas Hollenbach
Construction Specifications Institute

David Jeanes
American Iron and Steel Institute

David B. Johnson
U.S. Department of Agriculture
Forest Service

Bert Kimmel
Quaker Maid Kitchens

ATTENDEES (Continued)

Richard H. Kolodin
U.S. Air Force
Office of Deputy Chief of Staff,
Programs and Resources

James D. Long
U.S. Navy
Naval Facilities Engineering Command

Nicholas R. Loope
United Brotherhood of Carpenters and
Joiners of America

Charles T. Mahaffey
Center for Building Technology
National Bureau of Standards

Howard L. Metcalf
Office of the Secretary of Defense
Installations and Housing

Hans J. Milton, FRAIA [Speaker]
Australian Department of Environment,
Housing and Community Development
Technical Consultant to
Center for Building Technology
National Bureau of Standards

Raymond J. Moss
IBM Real Estate and Construction

Paul J. Muessig
National Association of Home Builders

Henning Orlando [Speaker]
Managing Director,
Swedish Building Standards Institute

Joseph L. Owens
American Plywood Association

Robert Packard, AIA
Architectural Graphic Standards

Bill Penoyar
U.S. Department of Commerce

Gerald F. Prange [Chairman of Meeting]
National Forest Products Association
Chairman, Construction Products Sector,
American National Metric Council

Buck Richardson
International Masonry Institute

Lee E. Rogers
U.S. Navy
Naval Facilities Engineering Command

Mary Roth
Door and Hardware Institute

William W. Seaton
National Association of Home Manufacturers

R.E. Shields
Society of American Registered Architects

Thomas Clark Tufts, AIA
Chairman, Construction Industries
Coordinating Committee
American National Metric Council

Professor Neil Wandmacher
Chairman, Engineering Design Subsector,
American National Metric Council

Charles Whitten
Chairman, Surveying and Mapping Sector,
American National Metric Council

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16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)* These edited proceedings are a summary of a Joint Conference of the Design Sector and Construction Products Sector of the Construction Industries Coordinating Committee of the American National Metric Council, which was held in Washington, D.C., on June 6, 1977. They may be used as a general reference document dealing with the background of and precedent in metric dimensional coordination.

As the United States prepares to join the metric building world, both the issues and relevant precedent in dimensional coordination become significant as a basis for an effective and economical change. To this end, the papers presented at this Joint Conference address the following topics:

1. Dimensional Coordination - An Industrial Management Tool, which reviews the issues and application of dimensional coordination;
2. Building Standards Development in Sweden and in the Metric Building World, which outlines issues in national and international standardization in the context of building design, production and construction dimensions; and
3. Metrication - The Opportunity for an Industry-wide System of Dimensional Coordination: Precedents and Issues, which reviews precedent in metrication and the simultaneous change to preferred building dimensions and preferred sizes in component production.

The questions and answers emanating from the Joint Conference reflect the concerns of the United States' design and production communities at the outset of metrication and dimensional coordination.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

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