DOCUMENT RESUME

ED 201 519 SE 034 915

AUTHOR	Milton, Hans J.; Berry, Sandra A.
TITLE	Metric Conversion in the Construction Industries--Technical Issues and Status.
INSTITUTION	National Bureau of Standards (DOC), Washington, D.C. Center for Building Technology.
REPORT NO	NBS-SP-598
PUB DATE	Oct 80
NOTE	152p.
AVAILABLE FROM	Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402 ($5.50).
EDRS PRICE	MF01/PC07 Plus Postage.
DESCRIPTORS	*Adult Education; *Construction Industry; Coordination; *Industrial Education; Information Dissemination; Mathematical Applications; *Mathematics Education; Measurement; *Metric System; Program Descriptions; Supplementary Reading Materials

ABSTRACT

This Special Publication was prepared at the request of the Metric Symposium Planning Committee of the National Institute of Building Sciences (NIBS). It is intended to provide information on technical issues and status of metric conversion in the United States construction industries. It was made available to attendees at the NIBS Symposium on "Metric Conversion in the Construction Community" which was held December 2-3, 1980, in Chicago, Illinois. In addition, it will be available to other affected parties in the construction community. The report contains information on planning for the metric change, current metric activities of professional and industry groups, technical implications in the construction industries, dimensional coordination, metric building products and services, research issues, and timing. It is intended to provide assistance for informed decision making relative to metric conversion for the U.S. construction industries. Also included in the report is a bibliography of relevant construction industries' metric technical information. (Author)

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Metric Conversion in the Construction Industries—Technical Issues and Status

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Issued October 1980

Library of Congress Catalog Card Number: 80-600173

National Bureau of Standards Special Publication 598
Nat. Bur. Stand. (U.S.), Spec. Publ. 598, 144 pages (Oct. 1980)
CODEN: XNBSAV

U.S. GOVERNMENT PRINTING OFFICE
WASHINGTON: 1980

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402
Price $5.50
(Add 25 percent for other than U.S. mailing)

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The report contains information on planning for the metric change, current metric activities of professional and industry groups, technical implications for the construction industries, dimensional coordination, metric building products and services, research issues, and timing. It is intended to provide assistance for informed decisionmaking relative to metric conversion for the U.S. construction industries. Also included in the report is a bibliography of relevant construction industries' metric technical information.

Keywords: Construction industries; dimensional coordination; metric bibliography; metric conversion timetable; metric decision; metric product sizes; metric system (SI).

PREFACE

This report has been prepared as an information paper for those considering issues related to conversion of the building industries to the metric system of measurement. In particular, it is made available for those attending the Symposium on "Metric Conversion in the Construction Community," to be held in Chicago, IL, on December 2-3, 1980.

The Symposium is being held under the leadership of the National Institute of Building Sciences (NIBS) in cooperation with the American National Metric Council, the United States Metric Board, and the National Bureau of Standards. The purpose of the Symposium is for the U.S. construction community:

> "To examine opportunities and problems relating to the metric system of measurement in construction and to consider a procedure for developing consensus on whether or not the construction community should convert, and, if so, when."

This report is designed to assist attendees by providing background information on the status of metric conversion in the United States and to provide a general understanding of the key aspects of metrication for the construction community. It was assembled from material provided by the U.S. construction community and technical data developed by the Center for Building Technology at the National Bureau of Standards. It is intended to present pertinent data and an analysis of the principal issues faced by the construction community. It is recognized that all of the content will not be of interest to many readers. Therefore the information has been carefully broken up and headlined so that the table of contents provides a guide to selective reading.

The report was requested by the NIBS Metric Symposium Planning Committee, which is comprised of representatives of the four organizations mentioned above. The material presented does not represent the formal position of any organization or individual, except where so indicated.

Special thanks are extended to the principal authors of this report, Hans J. Milton, FRAIA, Technical Consultant, and Sandra A. Berry of the National Bureau of Sandards. Mr. Milton's services on metrication and dimensional coordination were made available by the Australian Government with the support of the U.S. Department of Housing and Urban Development.

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ACKNOWLEDGEMENTS

Constructive comments on an earlier draft of this document were received from:

David S. Miller	Chairman, Metric Symposium Planning Committee, National Institute of Building Sciences
Louis Barbrow	National Bureau of Standards
A. Charles Danner	U.S. Metric Board
David Gorin	American National Metric Council
Charlene F. Sizemore	Board of Directors, National Institute of Building Sciences
Thomas C. Tufts	Chairman, Construction Industries Coordinating Committee, American National Metric Council

The authors express appreciation to Ms. Ulesia Gray, Center for Building Technology Word Processing Center, for her assistance in preparing this document for publication in a very short time frame.

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PART 1 - METRIC CONVERSION DELIBERATIONS AND PLANNING FOR THE CHANGE

1.1 Historical Background

The metric system of units was proposed at a time when the United States of America had just put into effect its Constitution, and George Washington had been named first President. In 1790, France, Great Britain, and the fledgling United States were all considering major changes to their systems of weights and measures in order to reduce diversity and confusion. In each case, uniform measures and a decimal base were proposed, but only in France was a system developed which has since been adopted by nearly all nations of the world--the "systeme metrique" or metric system.

Thomas Jefferson, the Secretary of State in 1790, was aware of Talleyrand's proposal to the French National Assembly for a new and radically different system of units, when he submitted as one of two plans for consideration an elegant concept of decimally related weights and measures, based on a decimalized foot and a decimalized pound, with a direct relationship to the cubic foot. Although Jefferson's support for a "decimal" currency had been instrumental in establishing the decimal concept of measurement as the basis of commerce and accounting, no action was taken to change weights and measures.

The first serious comparison of English (customary) and French (metric) measures was made in 1821, in the extensive "Report Upon Weights and Measures" by John Quincy Adams, stating advantages and disadvantages of both systems. Adams, however, counseled against any hasty decision and, thus, the subject remained dormant until the 1860's, when some major international conferences and the newly formed National Academy of Sciences took up the subject of an "international" system of measurement.

The result of new initiatives was that the metric system was authorized by an Act of Congress passed in 1866 (14 Stat. 339, July 28, 1866), and thus became permissible for use in any transaction.

In 1875, the United States became one of the original signatory nations to the Treaty (Convention) of the Meter (20 Stat. 709), which established the General Conference on Weights and Measures (CGPM), the International Committee for Weights and Measures (CIPM), and the International Bureau of Weights and Measures (BIPM). Thus, for over a century, the United States has actively participated in the development of the concepts of the metric system and, in recent years, the International System of Units (SI).

Since 1893, customary units for use in the United States have been defined in terms of metric units. In addition, all major units for electricity, magnetism, and illumination now in use in the United

States are metric units and, in most instances, pure SI; for example, watt, volt, ampere, ohm, siemens [mho], hertz [cps], weber, tesla, henry, candela, and lumen.

There have been various periods, starting in the 1860's and continuing into the 1970's, during which bills have been introduced in Congress to effect the adoption or wider use of the metric system. Hearings were held on many occasions, under the auspices of Senate or House of Representatives' committees [1]*.

Since the formation of the Congressional Committee on Science and Technology in 1959, which by House rule has been charged with the general oversight of the "standardization of weights and measures and the metric system," bills have been introduced that year and every year following to effect wider use of the metric system in the United States or to provide for surveys and studies to weigh the advisability of doing so.

In 1960, the United States was a signatory to the 11th General Conference on Weights and Measures, which formally gave the title "International System of Units" to the rationalized and coherent version of the metric system, for which the abbreviation "SI" is used in all languages. With this action, the change became an "international" issue, reflecting the international participation in the development of SI. Following a decision in 1965 by British industry to change to SI, based on a voluntary conversion, one by one all other English-speaking nations decided to replace their customary measurement systems with the International System of Units. Of the major nations, the decision by South Africa was followed by Australia, New Zealand, and Canada, so that by the mid-1970's only the United States had not reached a decision.

1.2 The U.S. Metric Study and Testimony from the Construction Industries

On August 9, 1968, the President signed Public Law 90-472 (82 Stat. 693), "An Act to authorize the Secretary of Commerce to make a study to determine the advantages and disadvantages of increased use of the metric system in the United States," also referred to as the Metric Study Act of 1968. The Act specified that the Secretary of Commerce should submit to Congress, within 3 years, a full and complete report of the findings, together with such recommendations as considered to be appropriate and in the best interests of the United States. The "U.S. Metric Study" was conducted by the National Bureau of Standards, and has been reported in a 12-volume U.S. Metric Study Interim Report (NBS SP 345-1 to SP 345-12) [2], as well as a Report to the Congress (NBS SP 345 - July 1971), entitled "A Metric America - A Decision Whose Time Has Come" [3]. The report concluded that the United States should

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* Numbers in brackets refer to references at end of each Part.

change to the metric system through a coordinated national program, and provided a number of more detailed recommendations, for example:

- that the Congress assign the responsibility for guiding the change, and anticipating the kinds of special problems described in the report, to a central coordinating body responsive to all sectors of society;

- that within this guiding framework, detailed plans and timetables be worked out by the sectors themselves;

- that early priority be given to educating every American schoolchild and the public at large to think in metric terms;

- that immediate steps be taken by the Congress to foster U.S. participation in international standards activities;

- that in order to encourage efficiency and minimize the overall costs to society, the general rule should be that any changeover costs shall "lie where they fall;"

- that the Congress, after deciding on a plan for the Nation, establish a target date 10 years ahead, by which time the United States will have become predominantly, though not exclusively, metric; and,

- that there be a firm government commitment to this goal.

As part of the U.S. Metric Study, the construction industries were asked to respond on their feelings about the projected change to metric measurement. This was accomplished by means of questionnaires and interviews, as well as by means of a two-day Construction Industry Conference, held at the National Bureau of Standards, U.S. Department of Commerce, on October 5-6, 1970.

The responses from the "contract construction" sector of nonmanufacturing businesses are detailed in U.S. Metric Study Interim Report No. 5 - Nonmanufacturing businesses (NBS SP 345-5). The following estimates were made by construction respondents as to a reasonable time period for the change:

	Percentage	Cumulative Percentage
Immediately	0%	0%
1 - 2 years	6%	6%
3 - 5 years	17%	23%
6 - 10 years	45%	68%
11 - 15 years	6%	74%
16 - 20 years	8%	82%
Over 20 years	4%	86%
Never	3%	89%
No answer or don't know	11%	
	100%	

The response indicates that a majority of the respondents who chose a time frame regarded a 6-to-10 year period as reasonable, namely 45/89 or 50.6 percent. If the responses favoring a shorter time frame are added, 68/89, or 76.4 percent, opted for a time frame within 10 years. However, when asked about the current attitude of *your company toward increased metric usage in your operations*, 37 percent of the construction companies indicated that they were mildly or strongly against against metrication, while 24 percent indicated that they were for metrication. The remainder--39 percent--were either neutral or noncommittal (no answer, don't know). Fifty-seven percent of construction representatives indicated that they believed increased metric usage was in the best interest of the United States.

Additional testimony from the construction sector was obtained with the assistance of the Construction Affairs Committee of the U.S. Chamber of Commerce. The testimony from 26 major construction related groups is summarized in U.S. Metric Study Interim Report No. 12 - Testimony of Nationally Representative Groups, pages 76 - 86. The summaries of findings have been reproduced as Appendix 1, as are the inputs from individual groups that gave testimony, including the construction industry's unions, whose testimony were presented at a separate National Metric Study Conference on Labor.

1.3 Legislative Action, the Establishment of the U.S. Metric Board

Following the U.S. Metric Study Report, legislation was forwarded to Congress by the Administration for a voluntary ten year plan to convert the nation to the metric system [92nd Congress]. However, no action was taken.

A number of bills were introduced in the 93rd Congress, with hearings held on them en bloc in March and May 1973, followed by the reporting-out of a metric bill by the Subcommittee on Science, Research, and Technology, which was amended in the full Committee in October 1973. On May 7, 1974, this bill was brought to the floor under a suspension of rules which requires a two-thirds vote, but it was not acted upon favorably.

In the 94th Congress, many bills were introduced in 1975, culminating in the reporting-out of H.R. 8674, which was subsequently considered and passed by the House on September 5, 1975; considered and passed by the Senate, but amended, in lieu of Senate bill S. 100, on December 8, 1975; concurred on the Senate amendment by the House on December 11, 1975; and signed into Law by President Ford on December 23, 1975, as Public Law 94-168, cited as the "Metric Conversion Act of 1975" [4].

The purpose of the Act is stated as "To declare a national policy of coordinating the increasing use of the metric system in the United States, and to establish a United States Metric Board to coordinate the voluntary conversion to the metric system." The Act does not specify a timetable for conversion, nor does it speak about the sole or predominant use of the metric system; rather, it mentions that "this Nation is the only industrially developed nation which has not established a national policy of committing itself and taking steps to facilitate conversion to the metric system," and that "it is therefore declared that the policy of the United States shall be to coordinate and plan the increasing use of the metric system in the United States and to establish a United States Metric Board to coordinate the voluntary conversion to the metric system."

The remainder of the Act deals with the establishment, structure, functions, and duties of the U.S. Metric Board, which, according to the Act, consists of a Chairman and 16 members appointed by the President by and with the advice and consent of the Senate. It is significant that Section 5.(b)(2)(H) specifies one of the members "to be selected from lists of qualified individuals representative of the construction industry." This gives the building and construction industries a direct voice in the deliberations of the U.S. Metric Board.

The original slate of nominees as Board members was rescinded after the change of Administration in 1976, and the official appointment of the U.S. Metric Board took place after the Senate had confirmed the first 13 nominees on March 21, and the other four nominees on June 20, 1978. The Chairman of the U.S. Metric Board is Dr. Louis F. Polk, of Dayton, OH, and the Vice-Chairman is Adrian Weaver of Stamford, CT. The member representing the construction industry is Francis R. Dugan, of Cincinnati, OH. The administrative offices of the U.S. Metric Board are located at 1815 N. Lynn Street, Arlington, VA 22209; Phone (703) 235-1933.

1.4 The American National Metric Council, and the Activities of its Construction Industries Coordinating Committee

As a result of increased metric discussion in the United States following the Report of the U.S. Metric Study in 1971, the American National Metric Council (ANMC) was formed in 1973. It was formed by private sector initiative and under the sponsorship of the American National Standards Institute (ANSI), as a nonprofit organization to assist all segments of the U.S. economy in the planning, coordination, and implementation of a voluntary change to the metric system of measurement.

In January 1974, representatives from the main segments of the construction industries met as a Steering Group for Building and Construction in ANMC, to establish strategies and policies for metric conversion activities. This Steering Group is now known as the Construction Industries Coordinating Committee (CICC).[1] Subsequently, a number of Sector Committees and Subsectors were formed to represent specific segments of the construction and allied industries and services. For the purposes of ANMC, these planning groups were given the following numeric codes:

3.00 CONSTRUCTION INDUSTRIES COORDINATING COMMITTEE [1974]

3.01 Design Sector [formed 1976]
Subsectors: Engineering
Architecture

3.02 Construction Codes and Standards Sector [formed 1975]
Subsectors: Building Codes
Electrical Codes
Plumbing Codes
Mechanical Codes
Elevator Codes
Fire Prevention Codes
State Implementation and Training
Canadian Code Liaison

3.03 Construction Products Manufacturers Sector [formed 1975]
Subsectors: Basic Structure
Exterior/Interior Finish and Insulation
Openings
Roofing
Mechanical/Electrical
Cabinets and Case Goods
Hardware

3.04 Contractor Sector

3.05 Information Sector

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1 The reference to Coordinating Committee in this text preceded the May 12, 1980, decision by the ANMC Board of Directors designating Coordinating Committees as Coordinating Groups.

3.06 Real Estate Sector [formed 1975]

3.07 Users Sector (Building Clients)

3.08 Surveying and Mapping Sector [formed 1975]

Also: Labor Liaison Committee (formerly Sector 3.05)

Participation in ANMC's planning activities for the construction industries has included more than 300 individuals, representing more than 150 industry associations or organizations.

During 6 years of meetings, the CICC and its various sector committees developed a comprehensive conversion plan for the U.S. construction industries. By March 1978, CICC had identified all key metric activities in all sectors then in existence and had related these activities in a series of logical networks showing interdependencies and sequences. These activity sequence charts for each sector and for the industry as a whole were shown publicly at the 4th Annual ANMC Conference in Atlanta, GA, in April 1978. During 1978, likely durations for the various activities were assessed, and in April 1979, at the 5th Annual ANMC Conference in Washington, D.C., a draft Construction Industries Metric Conversion Schedule was unveiled. This draft schedule provided the overall sector management program for metric conversion. In September 1979, the CICC and all its sector committees met to consider an expanded set of action schedules—or timetables—for each sector and the construction industry at large. These documents were subjected to the review by all individuals and groups associated with ANMC/CICC. In December 1979, the CICC met in Washington, D.C., and resolved to accept the timetable as a feasible basis for a voluntary change to metric, and decided to submit it for general approval and a commitment to change. On April 4, 1980, as a prelude to the construction sessions at the 6th Annual ANMC Conference in San Francisco, CA, the Metric Reporter [5] featured the ANMC/CICC Construction Industries Metric Conversion Timetable (figure 1-1). The Reporter also contained a ballot to permit individuals and/or organizations to express their feelings on the timetable.

The activities of the Construction Industries Coordinating Committee of ANMC, in attempting to develop a voluntary plan for metric conversion in the construction industries, have been detailed in the ANMC Construction Industries Coordinating Committee special publication (May 1980), "Metric Conversion in the Construction Industries...Planning, Coordination and Timing" [6].

This Timetable has not been submitted to the U.S. Metric Board for examination and general review in line with the procedures outlined in Section 6.(2) and 6.(3) of the Metric Conversion Act of 1975. These procedures state,

Figure 1-1: ANMC/CICC Draft Metric Conversion Timetable for the Construction Industries

AMERICAN NATIONAL METRIC COUNCIL
CONSTRUCTION INDUSTRIES COORDINATING COMMITTEE

CONSTRUCTION INDUSTRIES METRIC CONVERSION TIMETABLE

3.00 CONSTRUCTION INDUSTRIES COORDINATING COMMITTEE

Action Item	Lead Sector	Other Sectors Involved
Publish Metric Practice Guide for Construction (and Revise)	3.02	3.01 3.03 3.04 3.05 3.06 3.07 3.08
Develop Necessary Basic Metric Standards	3.02	3.01 3.03 3.04 3.05 3.06 3.07 3.08
Determine Product Sizes in Metric Units	3.03	3.01 3.02 3.04 3.05 3.07
Decision to Build Metric Building	3.07	3.01 3.02 3.03 3.04 3.05 3.06
Award Design Contract	3.07	3.01
Develop and Distribute Metric Product Literature	3.03	3.09
Produce Metric Measuring Equipment	3.03	—
Begin Conceptual Design in Metric	3.01	3.02 3.03 3.04 3.07
Publish Model Codes in Metric	3.02	3.01 3.03 3.04 3.05 3.06 3.07 3.08
Develop Metric Estimating System	3.04	3.01 3.03 3.07
Enact Enabling Legislation	3.02	3.01 3.03 3.04 3.05 3.06 3.07 3.08
Conduct Land Transactions in Metric	3.06	3.02 3.07 3.08
Produce Property Surveys in Metric	3.08	3.01 3.02 3.04 3.06 3.07
Begin Design Development and Engineering in Metric	3.01	3.02 3.03 3.04 3.07
Estimate and Bid on Metric Documents	3.04	3.01 3.02 3.03 3.05
Award Metric Construction Contract	3.07	3.01 3.04
Accept Plans in Metric and Issue Building Permits	3.02	3.01 3.04 3.07
Obtain Labor Agreements in Metric	3.05	3.03 3.04 3.07
Begin Construction of Metric Buildings	3.04	3.01 3.03 3.05 3.07
Deliver Metric Products to Suppliers and Site	3.03	3.01 3.02 3.05
Complete Metric Construction	3.04	3.01 3.02 3.03 3.07
Occupy and Maintain Metric Buildings	3.07	3.01 3.03 3.04
Conduct Real Estate Transactions in Metric	3.06	3.01 3.02 3.04 3.05 3.07 3.08

Year: 78 79 80 81 82 83 84 85 86 87 88 89 (M-DAY)

Schedule Code:

- Preliminary Metric Conversion Activity — More and more organizations become involved
- Intensive Metric Conversion Activity — Most of the required changes are made
- Decreasing Metric Conversion Activity — Any remaining changes are made
- Normal Metric Activity — Metric measurements have become predominant

Sector Number Code:

3.01	Design
3.02	Codes and Standards
3.03	Construction Products
3.04	Contractors
3.05	Labor Liaison
3.06	Real Estate
3.07	Users/Building Clients
3.08	Surveying and Mapping
3.09	Information

"In carrying out this program, the Board shall--

(2) provide for appropriate procedures whereby various groups, under the auspices of the Board, may formulate, and recommend or suggest, to the Board specific programs for coordinating conversion in each industry and segment thereof and specific dimensions and configurations in the metric system and in other measurements for general use. Such programs, dimensions, and configurations shall be consistent with (a) the needs, interests, and capabilities of manufacturers (large and small), suppliers, labor, consumers, educators, and other interested groups, and (b) the national interest;

(3) publicize, in an appropriate manner, proposed programs and provide an opportunity for interested groups or individuals to submit comments on such programs. At the request of interested parties, the Board, in its discretion, may hold hearings with regard to such programs. Such comments and hearings may be considered by the Board;"

The 23 Action Items of the Construction Industries Metric Conversion Timetable are analyzed and expanded in Part 8 of this publication.

1.5 The GAO Metric Report and Findings Relating to the Construction Industries

Following the passage of the Metric Conversion Act of 1975, concern was voiced by pro-metric as well as anti-metric groups about the implications of the Act. The General Accounting Office (GAO) undertook a study and reported to Congress on the implications of adoption of the metric system. It assigned a task force of GAO staff members to conduct a lengthy inquiry, involving both questionnaires and personal interviews, as well as analysis of available studies and documents.

On October 20, 1978, the Comptroller General released GAO Report CED-78-128, entitled "Getting a Better Understanding of the Metric System--Implications If Adopted By the United States." The 740-page Report to Congress and its Executive Summary [7] have not resolved the metric controversy in the United States, and contain no direct recommendations to Congress. However, on page 30-23, the Report states, "We believe, on the basis of the conversion lessons learned from the foreign countries experience, that if the United States is to be predominantly metric, the Congress should amend the Metric Conversion Act of 1975 to make it the national policy to convert to the metric system as the predominant system of weights and measures within a certain number of years. Also, the U.S. Metric Board should accept lessons learned in other countries."

The report emphasizes potential problems, concerns, and anticipated costs of the change and is, therefore, a useful guide to those areas which require additional research and investigation. In relying on "estimates," the report acknowledges that accurate assessments of either costs or benefits are not possible, but that the costs of the change would be substantial. The Report summarizes on page 31-27, "It would seem that as a minimum before voluntarily deciding to convert, there should be a clear understanding of the policy, knowledge of the costs and benefits involved, an assessment of the impact on the sector involved and any related sector, and a determination of the impact on consumers." Chapter 11 of the report, "Automotive Industry Provides an Impetus," deals largely with costs and benefits, and clearly indicates that initial cost estimates can be largely misleading and vastly overstated. In this industry, it is believed that the coupling of metrication with the introduction of new products or normal replacement cycles will result in benefits which will ultimately outweigh the costs.

The largest chapter in the GAO Report, Chapter 16, deals with the building and construction industries. The 55-page chapter, entitled "A Dilemma for the Building and Construction Industry," states some of the reasons why conversion is progressing at a slow rate. It also finds the industry, generally, is passive towards it, even though much of the industry considers conversion to be inevitable and beneficial for the United States as a whole.

"The apparent reasons for the lack of activity (at the time of the study--1976-1978) are that (1) the industry presently has no compelling reasons to convert, (2) the industry is uncertain of the national policy and Federal commitment to conversion, (3) parts of the industry are concerned about the costs and not certain of the benefits, and (4) it is difficult for individual firms or segments of the industry to act alone--the industry is too diversified, and no firm is large enough to lead. Metrication of the building and construction industry probably would not occur in the near future unless it is mandated or the Federal Government plays a greater role in bringing it about."

The chapter itself contains a great deal of useful information, based on the result of 285 usable replies to a construction industry questionnaire, sent to 394 industry associations, as well as quotes from interviews conducted with various industry spokesmen. In presenting responses to various questions, the report uses a breakdown:

1. Construction Industry Associations (285)
   a. Designers
   b. Contractors
   c. Labor
   d. Manufacturers
   e. Distributors
   f. Codes and Standards
   g. Real Estate
2. Small Construction Firms (67) from Survey of 1000 Small Businesses.

The categories of industry association, except for distributors, reflect the sectors adopted by the American National ~~Metric Council.~~

The GAO Study also asked a number of questions on timing of metric conversion in the construction industry, in Section F. of the Questionnaire (shown on page 16-55 of the Report).

Question 20. asked: "If the United States converts to the metric system, approximately what would be the shortest time frame for the majority of your members to convert?", and Question 21. asked: "If conversion is not made mandatory, what would be the optimum amount of time your members would need to convert?"

The GAO Task Force chose different time spans from those used in the U.S. Metric Study, having only two options rather than four options for the first 10 year period, and four options rather than two options for periods exceeding 20 years. Thus, the median in the eight GAO options falls at 20 years, compared with a median of 10 years in the eight U.S. Metric Study options.

Despite this difference in approach, the findings on timing were not dissimilar as indicated in the text on "conversion target dates" (pages 16-45 and 16-46), which is quoted in full below.

"[A] time frame is needed for the industry to properly plan and coordinate. Architects would know when metric products are available, and manufacturers would know when to produce metric products.

"Many factors should be considered in establishing a time frame. For example, some may want a time frame as short as practicable because of the dual inventories problem. Others may believe a longer time frame is necessary. The guiding principle should be to maximize benefits and minimize costs. More than one target date may be established for the industry with the time frame of one segment differing from, but coordinated with, that of others.

"About 90 percent of the associations and 77 percent of the small construction firms said that they could convert in 10 years or less. Sixty-three percent of the associations and 62 percent of the small construction firms thought that 10 years or less would be the optimum time frame for conversion; i.e., conversion could be most favorably implemented in 10 years or less."

Minimum Conversion Time Frame

Time Period	Associations	Cumulative	Small Construction Firms	Cumulative
Under 5 years	37%	37%	42%	42%
5 - 10 years	54%	91%	35%	77%
11 - 15 years	5%	96%	12%	89%
16 - 20 years	2%	98%	—	89%
21 years +	1%	99%	3%	92%
Never	1%	100%	7%	99%

Optimum Conversion Time Frame (Conversion not made mandatory)

Time Period	Associations	Cumulative	Small Construction Firms	Cumulative
Under 5 years	21%	21%	31%	31%
5 - 10 years	63%	63%	31%	62%
11 - 15 years	14%	77%	10%	72%
16 - 20 years	7%	84%	5%	77%
21 years +	5%	89%	3%	80%
Never	11%	100%	19%	99%

1.6 Involvement of the National Institute of Building Sciences

With the development of the draft of a Construction Industries Metric Conversion Timetable, representatives of construction industry associations working under the auspices of ANMC/CICC determined that a wider dissemination of the information and planning data should be made to all segments of the industry, to decide whether metric conversion was feasible, and, if so, whether it should be undertaken by means of a voluntary, private-sector led conversion program based on the ANMC/CICC timetable.

A cornerstone of the planning was the decision by the Construction Industries Coordinating Committee of ANMC that industry leaders should be acquainted with metric conversion issues, opportunities and concerns; as well as the metric conversion plan and schedule developed by ANMC/CICC. In September 1979, the National Institute of Building Sciences (NIBS)—as the major forum for the construction industry—was invited to be a sponsor of a national conference on metric issues and the ANMC/CICC Timetable, together with the American National Metric Council, the U.S. Metric Board (USMB), and the National Bureau of Standards (NBS).

Subsequently, NIBS decided that it should organize such a conference on a nonadvocate basis, with the assistance and cooperation of ANMC, USMB, and NBS. In that way, both pro-metric and anti-metric views could be presented in a construction-oriented context. The symposium on "Metric Conversion in the Building Industry" will be held in Chicago, Illinois, on December 2-3, 1980.

In February 1980, NIBS mailed a questionnaire on "Metric Conversion of the Building Industry" to all its members, to ascertain interest in attendance, and some feedback on: (1) aspects of metrication that have been researched; (2) the willingness of individuals to present a paper and the subject(s) for such a paper; and, (3) concerns about aspects of metrication. From responses it is clear that dimensional (modular) coordination and derived preferred sizes are regarded as the principal issues for the construction community.

1.7 International Metrication

Close contacts are being maintained by the ANMC, USMB, and standards-generating organizations with the Canadian building design, production, and construction industries to monitor their experiences during the transition to metric (SI) units, and to obtain information on any action that may assist the United States in making decisions on metric conversion. The Canadian building industry planned for an M-Day of January 1, 1978, and an M-Year of 1978, during which the actual changes in production and construction would be initiated, followed by a transition period of a few years and predominantly metric new construction by December 31, 1980.

In addition, information on approaches and metric practices developed during the changes in the construction industries of Britain, Australia, and New Zealand has been available to guide the United States in terms of technical precedent. But, rather than just following the patterns of other countries, analysis of precedent will indicate trends and make it possible for the United States to make decisions appropriate to its own needs and industrial patterns.

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PART 2 – CURRENT ACTIVITIES IN PROFESSIONAL AND INDUSTRY GROUPS AND STATE GOVERNMENT POLICIES, METRIC COMMITTEES OR COORDINATORS, METRIC ACTIONS

2.1 Current Construction Related Metric Activities

In the spring of 1980, the NBS Center for Building Technology sent a letter to 128 professional societies, trade associations, and individual companies requesting metric conversion information. This section of the document is comprised of excerpts from responses to this letter.

For the most part, those contacted are organizations which at sometime had representatives at a meeting of one of the Sectors comprising the Construction Industries Coordinating Committee of the American National Metric Council. In a few instances, organizations were contacted because they are well known in the construction community.

Following is a breakdown of inquiries sent and responses received separated into categories similar to the Sector divisions of the Construction Industries Coordinating Committee of the American National Metric Council.

Construction Related National Associations

Sector	Number of Inquiries Sent	Number of Responses
Design	13	9
Codes and Standards	19	10
Product Manufacturers	35	15
Contractors	9	3
Information	0	0
Real Estate	6	0
Surveying and Mapping	3	2
Labor Liasion	4	0
	93	39

Construction Related Individual Companies

Sector	Number of Inquiries Sent	Number of Responses
All Sectors	35	12

There were a total of 51 responses to the inquiry. Following is a summary of the information contained in these responses from Construction Related National Associations and Individual Companies combined:

Sector	Has Published Metric Information	Has Metric Policy	Has Metric Coordinator	Has Metric Committee
Design (10)	3	3	2	2
Codes and Standards (10)	6	2	4	2
Product (Mfgs) (26)	10	9	10	13
Contractors (3)	0	1	3	1
Information (0)	0	0	0	0
Real Estate (0)	0	0	0	0
Users (0)	0	0	0	0
Surveying and Mapping (2)	2	2	1	1
Labor Liaison (0)	0	0	0	0
	21	17	20	19

The following organizations responded to the inquiry:

Aluminum Association, The
American Association of Cost Engineers
American Concrete Institute
American Congress on Surveying and Mapping
American Hospital Association
American Institute of Architects
American Insurance Association
American Iron and Steel Institute
American Plywood Association
American Society for Testing and Materials
American Society of Heating, Refrigerating and Air-Conditioning Engineers
American Society of Mechanical Engineers
American Society of Photogrammetry
American Society of Plumbing Engineers
American Standard/U.S. Plumbing Products
Associated General Contractors of America
Association of Wall and Ceiling Industries - International
Bethlehem Steel Corporation
Bliss Steel Products Company
Brick Institute of America
Building Officials and Code Administrators International, Inc.
Business and Institutional Furniture Manufacturers Association
Carrier International Corporation
Concrete Reinforcing Steel Institute
Copper Development Association
Gypsum Association
Halstead and Mitchell-Division of Halstead Industries
Illuminating Engineering Society of North America
Interior Design Educators Council
International Association of Plumbing and Mechanical Officials
International Conference of Building Officials

Manufactured Housing Institute
Mechanical Contractors Association of America, Inc.
Mobil Research and Development Corporation
Monsanto Company
National Association of Home Builders
National Concrete Masonry Association
National Electrical Contractors Association
National Forest Products Association
National Society of Professional Engineers
Portland Cement Association
Prestressed Concrete Institute
Quaker-Maid - A Tappan Division
Red Cedar Shingle and Handsplit Shake Bureau
Society of American Registered Architects
Southern Building Code Congress International, Inc.
Tishman Research Corporation
Underwriters' Laboratories, Inc.
Union Carbide Corporation
United States Gypsum Company
Weyerhaeuser Company

A summary of each of the above organization's response follows in alphabetical order. Those organizations responding that have no metric conversion activity are included as well.

The Aluminum Association. The Aluminum industry, through committees of the Aluminum Association, has been preparing for metric conversion for over 9 years. The Association serves as secretariat to American National Standards Committee H35, which has published metric standards. The Association observes preferred metric sizes for metals established under American National Standards Committees B32.3 and B32.4. The Association has a metric committee which is chaired by Philip C. Althen, ALCOA, and J. W. Barr of The Aluminum Association is responsible for association metric activities. It published a "hard" metric version of its standards manual in 1978.

American Association of Cost Engineers. This association has a publication guide to authors which requires both customary and metric notation on all units in publications. Papers submitted containing SI units do not require English equivalents; however, the reverse is required. The Association expects to drop the use of English units altogether after a couple of years and publish exclusively in SI.

American Concrete Institute. The American Concrete Institute (ACI) has a 13-member Metrication Committee, chaired by Clarkson Pinkham, of S.B. Barnes and Associates, Los Angeles, CA. The mission of the Committee is: "To remain abreast of developments related to metric conversion and dimensional coordination, to evaluate the impact of these developments on the Institute and its membership, to assist the Board in coordinating the various Institute activities related to metrication and to recommend to the Board policies and objectives with regard to metrication and dimensional coordination."

In addition, the ACI Board of Directors has adopted the following metric policy:

> "It is the policy of the American Concrete Institute to support actively the use of the International System of Units (SI). Metric Conversion offers a unique opportunity to achieve greater dimensional coordination. The American Concrete Institute actively supports the development and implementation of a rational system of standard dimensions as a part of the processes of conversion to SI."

American Congress on Surveying and Mapping. This organization provided quite a lengthly response to the inquiry. It has been very active in the metric area and, therefore, its entire response is included.

Members of the surveying and mapping profession have discussed and written about the conversion to SI for many years. Since the signing of the Metric Bill by President Ford, the American Congress on Surveying and Mapping (ACSM), under the leadership of Dr. Charles A. Whitten, and in conjunction with the American National Metric Council, has prepared a guide entitled, "Metric Practice Guide for Surveying & Mapping."

Both ACSM and ASCE have affirmatively declared it a policy to assist in the orderly transition to the metric system. The ACSM charge for 1980 is:

> "Metric Committee (presidential)"
>
> The Metric Committee establishes and maintains liaison with appropriate federal agencies concerned with the adoption of the metric standard in the United States. Through ACSM periodical publications and such monographs as the "Metric Practice Guide," the committee provides up-to-date information on a continuing basis for the ACSM membership on the status of the application of the metric system in the United States as it affects various aspects of surveying and cartography. The committee continues to serve as the secretariat for the surveying and mapping sector of the American National Metric Council, supporting the views and interests of our professions before the ANMC, the U.S. Metric Board, and other agencies. The committee will, in cooperation with other societies and agencies, recommend a schedule of adoption of linear metric measurements by survey personnel and offices. Methods and degree of use should be considered.

In March 1980 at the annual convention of the ACSM and the American Society of Photogrammetry (ASP) in St. Louis, the following resolution was presented and adopted by the membership. It is currently being reviewed by the Board of Directors.

"Whereas, The President of the United States has signed the Metric Conversion Act (PL 94-168) in 1975; and

Whereas, The American National Metric Council has supported a voluntary conversion target date for 1985; and

Whereas, U.S. government agencies are in the process of conversion; and

Whereas, The U.S. Metric Board has provided leadership in coordinating conversion; and

Whereas, A smooth transition to the metric system as it pertains to land survey matters is in the best interest of the American people; Therefore, be it

Resolved, That American land surveyors have an obligation to prepare for conversion now;

Resolved, That land surveyors in private practice and in public service are urged to take the initiative in their daily performance of duties;

Resolved, That all new land survey plats and plans be prepared at a ratio scale whenever possible;

Resolved, That a dual bar scale in meters and in feet be shown on all land survey plats and plans;

Resolved, That, wherever possible, all areas be shown in m^2 or ha and that the equivalent in acres be added in parentheses on land survey plats and plans;

Resolved, That, wherever possible, all field surveys be executed with metric equipment and be recorded in metric units;

Resolved, That land surveyors join their state societies in assisting the public, their clients, attorneys, realtors, architects, and engineers in all relevant metric conversion matters."

In addition, the resolution was adopted by the New England Section of ACSM at its meeting in May 1980.

The Florida Society of Professional Land Surveyors is represented on the Florida Metric Council. In 1978 it published the Florida Metric Plan.

The U.S. Geological Survey has commenced publishing topographical quadrangle maps at ratio scales showing metric contour elevations in cooperation with several states.

The National Geodetic Survey of NOAA is currently advising and assisting state surveyors' societies in adapting legalized state plan coordinate systems to SI.

Many surveyors in private practice have begun to include meter/feet bar scales on their drawings. Also, the addition of square meters to the customary square footage and acreage of land is being added to land survey plans. A few surveyors have begun to show distances of boundaries in meters. Generally, it has been agreed that land title records be converted only when a new survey or subdivision takes place.

The response concluded:

> "The problem with surveying is that it is dependent upon the cooperation and consent of the legal profession, the real estate industry, architects, engineering and construction clients. As long as it is a voluntary method, it may become a matter of individual preference and may lead to undesirable disputes between various users of surveyors' plans."

The organization has a metric committee and Mr. Gunther Gruelich is its Chairman.

American Hospital Association. This association has monitored two aspects of metric conversion: (1) the impact it would have on any management or operational concern in hospitals, and (2) the effects it would have on the health facility. Although it has issued no material or publications to its members, the American Hospital Association is highly interested in other organizations that have developed useful guidance in the metric conversion subject area.

The American Institute of Architects. The American Institute of Architects (AIA) metric coordinator is Robert T. Packard, of Washington, D.C. Following is the AIA policy on metric conversion:

> "Policy Statement That the Board of Directors of the American Institute of Architects supports the Metric Conversion Act of 1975 (P.L. 94-168) as related to the construction industry, and further urges that the metric system be adopted as the national standard of weights and measures in the United States of America."

An "AIA Metric Building and Construction Guide" has been developed and was published by Wiley Interscience, Inc. A metric sounding board of AIA members interested in the conversion process has been established. These members are kept informed of metric events, and individuals are asked to attend and report on metric meetings affecting the construction industry.

The Board of Directors at its May 28-30, 1980, meeting adopted the following policy:

"The Board of Directors approves the ANMC/CICC Metric Conversion Timetable for the U.S. Construction Industries establishing January 1, 1985 as the date on which metric construction may begin in the United States."

American Insurance Association. The American Insurance Association has no metric publications; however, staff members have attended meetings of the American National Metric Council and it does have an interest in metric conversion.

American Iron and Steel Institute. The American Iron and Steel Institute (AISI) has had a Metrication Planning Committee for some years. It has been concerned primarily with metric issues such as proper use of units, questions of precision and training methods, which arise in processing steel ordered in the metric system through the plants--from order processing to shipment. It has published a Metric Practice Guide.

American Plywood Association. The American Plywood Association has a metric advisory committee which has recommended the metric panel size of 1200 x 2400 mm for sheathing grades of plywood. The committee voted to recommend panel thickness designation at the lower end of tolerances--no minus tolerances. Metric equivalencies for plywood sizing were also adopted. Work is underway on metric thicknesses for sanded panels.

American Society for Testing and Materials. The American Society for Testing and Materials (ASTM) has a Metric Practice Committee--E43--whose proposed scope is:

The committee shall develop and maintain standards relating to the modern metric system (the International System of Units, SI) and its use. To facilitate carrying out this function is shall maintain a continuing surveillance of activity and practice in metric acceptance and use. The committee will provide advice and coordination on metric practice in standards and other publications for other ASTM technical committees. This committee will coordinate its work with that of other organizations having mutual interests.

The Committee Chairman is John F. Corey, Shelby, NC. The ASTM has published several standards. These are included in Part 9 of this report. The basic ASTM policy is:

"...that SI units of measurement shall be included in all ASTM standards that do not contain a companion standard in 'hard' metric units."

In addition to the general policy of ASTM "to include metric (SI) unit in all of its publications," the main national standards committee in the United States dealing with building standards—Committee E6, Performance of Building Constructions—has established the following metric policy:

> "E6 standards (old and new) submitted to Society for approval shall be written henceforth with SI units and U.S. Customary in brackets, e.g., 100 mm [3.94 in.] or 25.4 mm [1.00 in.]. Hard or soft conversion remains the prerogative of the subcommittee writing the standards."

American Society of Heating, Refrigerating and Air-Conditioning Engineers. The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has a standing metric committee, which meets twice a year and is active in educating society membership on metric conversion. All ASHRAE publications will be in dual units commencing in 1981. The staff metric coordinator is Thomas C. Elliott, New York, NY, and ASHRAE's metric policy is as follows:

"1. All ASHRAE documents published after January 1, 1976, shall be prepared using only SI units, or shall be prepared using dual units, i.e., SI and conventional units, with the sequence of units left to the discretion of the author or editor. Exceptions in Handbook volumes, Standards, and special publications may be authorized by the responsible ASHRAE Metric Committee.

2. Except where difficulties would be encountered in achieving the stated purpose, the Handbook Series, starting with the 1981 Fundamentals Volume, shall be published using dual units. Chapters presently utilizing SI metric only shall remain so.

3. Exclusive use of SI units shall be required in ASHRAE publications when it is determined by the Board of Directors to be in the best interest of the membership. During the transition period, the Metric Committee will continue to disseminate educational materials to prepare the membership for the eventual exclusive use of SI units."

American Society of Mechanical Engineers. The American Society of Mechanical Engineers (ASME) has no metric coordinator; however, it has a metric consultant who serves as secretary of its Metric Study Committee. The ASME is the sponsor of the Boiler and Pressure Vessel Code, and presently has no plans to publish a metric edition. Following is ASME's metric policy (as updated in 1977):

> "The Society supports a coordinated voluntary national program of conversion to the International System of Measurement. ASME will cooperate with other organizations and societies in implementing

this policy. The ASME interpretation of SI is contained in <u>ASME Guide SI-1, ASME Orientation and Guide for Use of SI-Metric</u>.

All works, papers and periodicals published by the Society shall require units to be in the International System (SI). Customary units may also be included.

The Council directs the Policy Board, Codes and Standards to assure that Codes and Standards shall be published in SI units at the appropriate time as determined by industry, government, public and society needs consistent with national plans for coordinating and managing development of SI Standards."

<u>American Society of Photogrammetry</u>. The American Society of Photogrammetry (ASP) has the following statement in the Foreword to its publication "American Society of Photogrammetry Usage of the International System of Units":

"It is the policy of the American Society of Photogrammetry to promote simplification and uniformity in usage of units of measurement by cooperating with other organizations in establishing common use of the International System of Units (Systeme International d'Unites) with the abbreviation SI and popularly known as the 'metric system,' and to use this system in all of its publications.

This standard was prepared by the Standards committee of the American Society of Photogrammetry to promote use of the International System of Units, to make the policy of the Society known, and to make the rules of use of the SI units readily available to the members of the Society."

This standard is largely based on and generally technically consistent with Standard 1000 of the International Organization for Standardization.

<u>American Society of Plumbing Engineers</u>. This Society uses dual units in its publications entitled, "Data Book, Volume I, Fundamentals of Plumbing Design," 1979-1980 Edition, and "Solar Energy System Design," as well as an appendix on SI unit conversions. Customary units are shown first with SI "soft" converted units in parentheses. The Society's metric coordinator is A. J. Morales, Sherman Oaks, California.

<u>American Standard/U.S. Plumbing Products</u>. This organization uses dual dimensioning on cataloged products and its metric coordinators are J. S. Genovese and J. H. Bauer, New Brunswick, NJ. In his response to the inquiry Mr. Bauer stated, "As a member of a subcommittee of CICC, we have agreed to accept the tentative schedule [ANMC/CICC Metric Conversion Timetable] put forth by CICC."

<u>Associated General Contractors of America</u>. The Associated General Contractors of America (AGC) has the following metric policy:

"...If the (construction) industry is to go metric, a hard conversion is recommended where there is an economic advantage (e.g., reduction of number of sizes). This means that the sizes of building products will change. In order to insure sensible change, sizes will have to be coordinated and rationalized. A hard conversion properly handled, involving dimensional coordination is thus necessary if the building and construction industry is to realize any advantage from metric conversion."

The AGC has taken no position for or against metric conversion. The AGC has had a metric conversion committee since 1974 and Campbell Reed, Washington, D.C., serves as its secretary. This committee has recommended support of and participation in the December 2-3, 1980, Metric Symposium.

Association of Wall and Ceiling Industries - International. This association has published no data in the metric area. It has established recently a task group on metric conversion from within its Technical Committees. Mr. Gene Erwin, Washington, D.C., is responsible for Association metric activity.

Bethlehem Steel Corporation. Bethlehem Steel has the following metric policy:

"Bethlehem Steel recognizes that the metric (SI) system is to become the predominant system in the United States. We intend to supply metric-dimensioned products to our customers when it is practical to do so--from their point of view as well as ours. We intend to remain fully aware of the progress being made by our customers in implementing their metrication programs in order that we can do what is necessary at the best possible time."

The Corporation has had a Corporate Metrication Committee since 1973. It is chaired by A. G. Oudheusden, Bethlehem, PA. The Committee is composed of department heads and its purpose is to study and make recommendations for converting operating procedures and practices, processes, facilities, products, etc., to the metric (SI) system so as to supply metric-dimensioned products when market demand dictates.

Bethlehem can accept and supply metric orders for flat-rolled steel products. Other products can be supplied on a soft converted basis, i.e.; structural shapes, castings, forging, etc. Structural bolts can be supplied to metric ASTM specifications.

The Chairman of the Corporate Metrication Committee summarized, "...we have seen little interest in metric conversion so far, except for a few large steel customers with worldwide operations in the automotive and equipment areas."

Bliss Steel Products Corporation. The President of Bliss Steel has been involved in activities of the Contruction Industries Coordinating Committee of the American National Metric Council. In his response, he stated "The timing on our metrication will depend upon the metrication of the entire Building Industry."

Brick Institute of America. The Brick Institute of America (BIA) has no formal metric policy. Its Engineering and Research Committee is acting as its Metric Committee, with Alan H. Yorkdale, McLean, VA, serving as coordinator. The response from the BIA included the following:

"Approximately three (3) years ago, the brick industry of the United States was surveyed by the Institute. The general questions related to metric conversion and dimensional coordination, along with metric conversion.

The result of the survey indicated a general wait-and-see attitude, with approximately 80 percent responding that 'when and if conversion came about,' they were willing to convert to dimensionally coordinated metric size units.

It is significant to note that all manufacturers who are now making modular size standard units are, in fact, making 'metric modular' size units, within the tolerances of the material specification standards. All units larger than 'standard' size are now modular and will also satisfy 'metric modular.'

There are, of course, several 'special' sizes, mostly regional in manufacture and market area."

Building Officials and Code Administrators International, Inc. The Executive Committee of the Building Officials and Code Administrators International, Inc. (BOCA) reviewed the subject of metric conversion in June 1979. Final action on this subject was to be decided at the 1980 Annual Conference, with results in the 1981 Editions of the Basic Building Code, Basic Plumbing Code, Basic Mechanical Code, Basic Fire Prevention Code, and Basic Property Maintenance Code. The change will be a soft conversion.

Business and Institutional Furniture Manufacturers Association. This Association has a Metric Conversion Subcommittee which is a part of its Engineering Standards Committee. The output of this Association could be classed as part of the construction industry or the metal or wood manufacturing industry.

One of the primary functions of this Association is the preparation of safety standards. To date, it has published dual-dimensioned standards on general office chairs, lateral files, vertical files, and upholstered furniture flammability requirements. In the near future it expects to publish standards regarding desks, office panels and partitions, and lounge furniture in dual units.

<u>Carrier International Corporation</u>. Since 1975, Carrier Corporation has had a metric policy and placed responsibility for control of SI metric development and coordination services among divisions within the Corporate Engineering function. Two divisions of Carrier—Carrier International Corporation and the Elliott Company—both have implemented plans to meet the demands for SI units in overseas markets. The coordinator in each of these organizations is: Gerald Callahan, Corporate Engineering, Syracuse, NY; John Grecean, Carrier International Corporation, Syracuse, NY; and, Lionel Taylor, Elliott Company, Jeannette, PA.

<u>Concrete Reinforcing Steel Institute</u>. This Institute does not issue materials standards. It does participate in the development of metric specifications for reinforcing bars through the American Society for Testing and Materials. It is expected that the 1983 edition of the American Concrete Institute Building Code for concrete construction will be in dual units—metric and English.

The response included the following statement:

> "Our industry cannot produce metric sizes until it receives orders for same. The U.S. structural engineers cannot design for metric sizes until: (1) the Building Codes are adopted in metric, or (2) the Federal government requires all construction it finances to be in metric sizes and grades. Whenever these conditions are met, conversion of our industry will be quite rapid as substitution of present sizes from inventory is not difficult."

<u>Copper Development Association</u>. Mr. Arthur Cohen, Supervisor of Standards and Safety Engineering, New York, New York, serves as the focal point for metric activities for the Association.

<u>Gypsum Association</u>. The Gypsum Association has a metric committee consisting of 16 members. The Committee is chaired by R.P. Entz, of Des Plaines, IL. Its Vice Chairman and Secretary are D.L. Cook of Dallas, TX, and H.B. Carlsen of Evanston, IL, respectively. The Committee has developed a listing of gypsum products and soft converted their sizes to metric equivalents. It has a position paper opting for a soft rather than hard conversion of board products if metric is adopted in the United States. In response to a U.S. Metric Board call for general research proposals a recommendation for a project was developed with the objective, "To evaluate the effect and primarily the economic impact to both producer and applier alike if panel and tile products were produced (sized) based on the 100 mm module as opposed to the present 4-inch module.".

<u>Halstead and Mitchell - Division of Halstead Industries</u>. This organization to date has had no incentive to convert to SI units. Its

Engineering Department has had no difficulty in handling occasional inquiries in SI units. The organization belongs to the Air-Conditioning and Refrigeration Institute and this Institute's standards are published in dual units at present.

Illuminating Engineering Society of North America. The Illuminating Engineering Society (IES) adopted a policy in 1979 to use SI units as primary units in its new reports and technical publications. Inch-pound units are shown in parentheses for soft (exact) conversion and in brackets for hard (approximate) conversion immediately after the SI units. The IES Lighting Handbook is being revised (1980) and will contain SI units as primary units and, where possible, metric values will be nominal values.

Interior Design Educators Council. The organization has not taken an official position on the use of the metric system in teaching design. However, some of its members do teach some of their design problems in the metric system. The contact person within this organization is Mr. Curt Sherman, Richmond, VA.

International Association of Plumbing and Mechanical Officials. The International Asssociation of Plumbing and Mechanical Officials (IAPMO) metric coordinator is John Meacham, Los Angeles, CA. The IAPMO added metric equivalents to its Uniform Plumbing Code in 1977, and they are in the current edition (1979) of the Code. In addition, metric equivalents are contained in The Uniform Plumbing Code Illustrated Training Manual and the Uniform Solar Energy Code. Other codes will be brought into line as time permits.

International Conference of Building Officials. The International Conference of Building Officials (ICBO) has drafted, for internal use, proposed revisions to its codes and standards, in expectation that it should be ready to integrate metric units into the publications when the onstruction industry in general, has signaled it is ready to proceed. ICBO's contact person is Donald Watson, Whittier, CA.

Manufactured Housing Insitute. The Manufactured Housing Institute (MHI) has taken the following position relative to metric conversion:

> "The Manufactured Housing Institute (MHI) supports the principle of metric conversion but defers to the site-built housing component of the shelter industry in pursuing change-over. MHI sees no compelling reasons to expedite conversion, although there appears to be a consensus that benefits of total conversion should outweigh the nominal direct costs."

In addition, the response included MHI's Metric Conversion Concerns:

"Considerable planning and coordination must precede conversion. Manufacturers will have to work closely with suppliers of raw materials and finished components. The transition period may be difficult, for example:

1. There is a tremendous amount of technical documentation that must be republished. Standards that have taken years to evolve through the consensus process will have to go through it again to resolve which way to round off measurements. The cost of replacing entire technical libraries must also be considered.

2. The materials purchased by the industry will not all be available simultaneously in the metric system. Therefore, there will undoubtedly be periods of phasing out of English system materials and phasing in of metric materials. This will require periods of dual dimensioning and dual inventories.

3. The international building module of 100 mm and selected multiples sounds simple enough, but at some point in time standard joist, stud, and truss spacing must change from 16" (406.4 mm) to 400 mm (15-3/4"). We will have to use up inventories of 48" wide sheets of plywood, particleboard and ceiling panels.

4. The dual dimensioning problem and change-over date is not just a problem of purchased materials and inventories. It has significant impact on plant production jigs, fixtures, and tooling as well.

5. Retraining people will be a significant task all by itself. Teaching nontechnical people is sometimes difficult. The retraining will involve not only the unskilled workers in the plants, but some people who might be considered as having a reasonable education including inspectors at all levels.

6. The Metric Conversion Timetable comes as somewhat of a surprise. The dates shown indicate that the development of basic metric standards is well underway, but we have not yet seen any of them. Perhaps the schedule has slipped.

<u>Mechanical Contractors Association of America, Inc.</u> This Association has a Metric Coordinator, Thomas K. Whitesel, Jr., Washington, D.C.

<u>Mobil Research and Development Corporation</u>. The Mobil Research and Development Corporation has a metric committee and its Corporate Metric Coordinator is F. E. Ray of Princeton, NJ. In his response to the inquiry, the Metric Coordinator voiced a concern that there were no process plant constructors participating in the Construction Industries Coordinating Committee of the American National Metric Council.

<u>Monsanto Company</u>. Monsanto follows prevailing practice in the country where the facility is being constructed. When special purpose equipment designed and built in a "metric" country is used in the United States, in some cases "inch/pound" drawings are made to facilitate installation; in other cases the construction people interpret and follow the metric drawings, as supplied.

Monsanto does not feel it is its role to pioneer the use of metric SI units in the construction industry, but is prepared to move to the metric system if and when the U.S. construction industry does so.

National Association of Home Builders. The Board of Directors of the National Association of Home Builders (NAHB) passed the following resolution relative to metric converison on May 15, 1978:

Construction and Savings Committee

"WHEREAS, all industrialized countries other than the United States have adopted, or are in the process of adopting, the metric system as their sole method of measurement; and

WHEREAS, there is increasing discussion from within the United States and abroad for the United States to establish a program incorporating a timetable for converting from the English system to the metric system; and

WHEREAS, the United States Government has enacted the 'Metric Conversion Act of 1975' which declares a national policy of coordinating the increased use of the metric system; and

WHEREAS, leadership is needed within the construction industry to implement metric conversion when it occurs; and

WHEREAS, various agencies of government are becoming involved in metrication which could possibly lead to taking the initiative away from the private sector; and

WHEREAS, the potential savings to the construction industry are enormous by an orderly conversion,

NOW, THEREFORE, BE IT RESOLVED that NAHB support the American National Metric Council's initiative in channeling and organizing the private sector's effort to date in making the ultimate changeover to the metric system an orderly and beneficial one."

The NAHB has been involved with metric activities for several years, has had representation on the Board of Directors of the American National Metric Council, as well as a number of Sector committees.

The homebuilders are concerned with the lack of documented evidence to prove claims of savings to the construction community. There is concern that a conversion may cost the industry a sizable amount of money, because of the complexity of the industry's make-up.

The NAHB staff persons assigned responsibility for metric involvement are Robert Boras and Milton Smithman, both of whom are located at NAHB headquarters in Washington, D.C.

Mr. Smithman concluded his reply with:

"We sincerely support the conference which is to be sponsored by the National Institute of Building Sciences on the subject of [Metric Conversion in the Construction Industry]. We believe it to be very constructive to air the issues both pro and con with the participation of all parties involved. Hopefully, this conference will result ultimately in some sort of unified position."

National Concrete Masonry Association. This association responded negatively to the inquiry and the response is included here in total.

"Our organization has been against metric conversion from the beginning, and the more it is studied, especially with the Canadian experience now in progress, our position remains unchanged.

"Since our product is made and sold only in the U.S., we see no advantage to changing to metric. The costs to convert to metric will be in the order of $140 million with most of the money being spent rather quickly since all the molds which are used for the manufacture of concrete masonry would have to be made anew. There are currently about 1500 different sizes and shapes of concrete masonry being made in the U.S. and one concrete masonry manufacturing plant will normally make from 50 to 200 different sizes and shapes.

"Our organization prints more literature on concrete masonry than any other in the world and we employ metric designations in most of our literature since it is read all over the world. Therefore, we are not unfamiliar with metric dimensions - or its problems. We find countries which have adopted metric sizes have had problems on agreeing on common dimensions so metric is not an answer to 'being in step with the world.'

"We are staying informed on metric progress, and view with alarm how quickly some industries are adopting the principle. For international organizations, there is merit in going to some type of metric scaling, but for domestic organizations, the costs of conversions are horrendous without much economic benefit.

"We will have [a representative] at the meeting in December, but not as an advocate of metric conversion."

National Electrical Contractors Association. The Metric Coordinator for this association is Charles J. Hart, Associate Director, Services and Codes, Washington, D.C. In his response to the inquiry, Mr. Hart stated:

"...the National Electrical Contractors Association does not believe that it is in a position to either promote or to impede metric conversion in the construction industry. If such conversion is determined, we believe that it should be orderly and coordinated. We are members of the American National Metric Council and participate in several sectors of the Construction Industries Coordinating Committee."

National Forest Products Association. The National Forest Products Association published a booklet entitled, "Lumber and Wood Products Metric Planning Package," under the auspices of the Lumber and Wood Products Sector Committee of the American National Metric Council. In his response, the Vice President of Technical Services of the Forest Products Association stated that the wood industries steadfastly held to a policy of non-advocacy of metric conversion throughout the development of this booklet. After its completion, the Sector committee and its components decided to adopt a holding action pending a positive indication of metric progress on the part of the Federal government or the construction industry.

National Society of Professional Engineers. The National Society of Professional Engineers is concerned with the professional, rather than technical, aspects of engineering; therefore, its primary role with respect to conversion to the International System of (metric) Units--SI, has been that of encouraging orderly transition and furnishing information to the membership via the Society's publications.

The Society has adopted the following professional policy:

> "PROFESSIONAL POLICY NO. 102-C
> METRIC SYSTEM--CONVERSION TO
>
> The National Society of Professional Engineers, recognizing the advantages inherent in use of the metric system of measurement, endorses the principles embodied in the Metric Conversion Act of 1975.
>
> In implementing the Act, NSPE supports full conformance with the SI metric standards of the International Bureau of Weights and Measures and in the matter of spelling with the standards of the consortium of English speaking countries of the world.
>
> NSPE urges it members, chapters, and state societies to provide any assistance it can to further the rapid conversion to the metric system within the United States."

Portland Cement Association. The Portland Cement Association (PCA) has a Metric Committee whose principal objectives are to:

1. provide such technical assistance to the Canadian Portland Cement Association as may from time to time be requested to implement their metric needs;

2. keep informed on the various activities directed to promoting U.S. metric conversion, and, when deemed necessary, notify our member companies on current events and important issues;

3. evaluate the probable impact on PCA operations which may eventually result from U.S. metric conversion; and,

4. plan programs within PCA to implement metric conversion, but only at such time as the nation voluntarily decides to convert and a national M-date has been established and accepted.

The PCA response included the following note:

> "It must be clearly undersood, however, that PCA does not in any way set the metric policies for the cement industry, nor does it represent its members, collectively or severally, in any matters concerning metric conversion. Metric policies, planning and programs are strictly the responsibility of each cement producer, acting independently for its own interests, and, therefore, a consensus industry attitude towards metric conversion has not been established."

The PCA has researched and prepared several hard metric publications and design aids for the Canadian cement interests. All publications written since 1978 contain soft conversion of English units.

Prestressed Concrete Institute. The Prestressed Concrete Institute (PCI) has a Metrication Committee, chaired by Douglas C. Jeffords of Nashville, TN. Mr. Daniel P. Jenny of Chicago, IL is PCI's Metric Coordinator.

PCI has the following metric policy, dated January 1978:

> "The Prestressed Concrete Institute endorses metric conversion to the SI system of measurements. It is imperative that the conversion be done in a well planned, orderly fashion in order to minimize the difficulties that will result from the conversion, as well as to assure that the various standards adopted for use in the prestressed industry are logical and compatible. Hence, it is the policy of the Institute to continue to monitor the steps being taken toward metrication in the construction industry with the view of assisting the conversion and achieving reasonable and workable standards."

In his response, the Metric Coordinator included the following "Initial Steps for Implementation of the PCI Board Policy on Metrication:

1. All new PCI publications including PCI periodicals will have soft conversions, i.e., metric equivalents in parentheses, metric scales on graphs where feasible, and metric conversion charts.

2. When existing publications are revised they shall have a soft conversion.

3. PCI shall adopt the 100 millimeter module as a basic unit (approximately 4 inches).

4. PCI shall adopt a basic panel size of 1200 x 2400 millimeters (approximately equivalent to 4.0 x 8.0 feet).

5. The Standardization Committee shall be directed to use this opportunity for the rationalization of a reduced number of shapes. When reviewing and cataloging this information, it shall be looked at in both hard (exact) metric units and customary (English) units.

6. PCI shall expand its educational activities to assist the members in evaluating and understanding metric conversion, and the SI system of measurement.

7. The Metrication Committee shall be responsible for developing a hard conversion metric plan and schedule and recommend the appropriate time for implementation.",

Quaker Maid - A Tappan Division. This organization is awaiting the resolution of differences between the paneling plywood industry and gypsum paneling industry. One industry is ready to convert to a 1200 x 2400 mm panel, while the other wishes to maintain the 4' x 8' measurement. Until these differences are resolved, the cabinet and appliance industry cannot proceed, as many cabinet dimensions have developed over the years to efficiently use plywood paneling.

Red Cedar Shingle and Handsplit Shake Bureau. To date, the extent of this organization's metric activities is the inclusion of metric units on the labels of bundles of shingles and shakes, i.e.,

16" x 5/2"	(400 mm x 5/50 mm)
24" x 3/4"	(600 mm x 19 mm)

Society of American Registered Architects. This Society responded saying that for several years a representative has been attending meetings of the Design Sector of the Construction Industries Coordinating Committee of the American National Metric Council. Bernard L. Frishman, Silver Spring, MD, is Coordinator and Representative for the Society.

Southern Building Code Congress International, Inc. The Southern Building Code Congress International, Inc. (SBCCI) has no formal timetable for conversion to SI units, and feels the industry itself should provide information and guidance on which units it will convert to. A metric conversion chart is included in all 1979 editions of the Standard Codes, and SBCCI is beginning to incorporate metric units in Research and Compliance Reports it issues on products and materials. The SBCCI Board is considering including soft converted units for nonindustry dimensions in its 1982 Standard Codes; i.e., stair dimensions, heights and areas, door widths, etc.

Tishman Research Corporation. The Tishman Research Corporation has neither a metric policy nor a metric coordinator. This organization posed questions in its response to the inquiry which are answered at the beginning of Part 2.

Underwriters' Laboratories, Inc. In 1972, Underwriters' Laboratories, Inc. began including SI metric equivalents to the stated customary units in its Standards for Safety. Most standards include soft converted units; however, when the involved industry expresses the need, hard converted values are used.

Union Carbide Corporation. Union Carbide's Metrication Coordinator is C.S. Hines, South Charleston, WV. It has a metrication Steering Committee which includes contacts in all divisions and functional groups. The Steering Committee meets twice a year and maintains close contact otherwise by telephone and Metric Bulletins issued by the Coordinator. Some of its executives have had overseas experience and are familiar with international use of metric. Union Carbide produces and sells some products in metric in the United States and is preparing to do so in many remaining products. Market demand and other considerations determine the timing of implementation of Union Carbide's metric conversion plans.

United States Gypsum Company. This company has a major concern with the replacement of the 4-inch module with the 100 mm module. It is opposed to hard conversion of panel, tile, and block products. It opposes neither "soft conversion" nor "hard conversion" of non-rigid products which are sold in bulk and/or packaged in bags, boxes, cans or similar volumetric units.

U.S. Gypsum established a corporate policy in 1978, as follows:

> "United States Gypsum Company recognizes the apparent inevitability of the proposed use of metric (SI) units as a replacement for those units such as inch, pound, and foot, generally employed in the United States.
>
> The conversion of rigid materials to "hard" metric sizes based on the 100 mm module is not believed to be in the best interest of the Company, the construction industry, and the public in general. The manufacture of gypsum, wood and mineral fiber products in sizes based on the 100 mm module would result in smaller sizes than are presently produced with the 4-inch module and therefore a loss of

manufacturing capacity, an increased use of energy, and a requirement for additional labor for installation. Therefore, it will be Company policy to support change on a "soft" conversion basis only on rigid products. In anticipation of such change, labels and literature will have metric values added at such time as revisions are made normally.

Conversely, 'hard' conversion of products sold by weight or volume such as building plasters, joint compounds, fluid paints, and adhesives would have little effect on capacity and therefore could readily be converted at such time as metric is accepted in the United States. Company policy will be to accept 'hard' conversion of measurements for such products."

The Company carries dual labeling on a large percentage of its products, much of its literature and all research reports carry dual units, and it is presently converting asphalt roofing shingles to hard metric sizes. Mr. R. P. Entz of Des Plaines, IL is the metric coordinator for the U.S. Gypsum Company.

Weyerhaeuser Company. Mr. Jack Firkins, Tacoma, Washington, is the Metric Coordinator for Weyerhaeuser. The company has issued a Weyerhaeuser Metric Practice Guide. Its Senior Management Committee adopted the following policy in 1976.

"In recognition of increasing international trade, the national policy of increasing metric use and the long-term benefits of metrication, it is the policy of Weyerhaeuser Company to support the adoption of metric units of measure known as the International System of Units (SI). It is our desire that metrication should be essentially complete by 1982. However, our adoption pace will be established considering our international product involvement, new product introduction and the metrication activity and progress nationally and within our industry segments.

Section 6, Item 4 of the Metric Conversion Act of 1975 instructs the U.S. Metric Board to 'encourage activities of standardization organizations to develop or revise, as rapidly as practicable, engineering standards on a metric measurement basis, and to take advantage of opportunities to promote (A) rationalization or simplification of relationships, (B) improvemments of design, (C) reduction of size variations, (D) increase in economy, and (E) where feasible, the efficient use of energy and the conservation of natural resources.' It is company policy to be actively involved in the development and revision of standards and codes relevant to the products we produce. This activity shall be coordinated through appropriate industry associations and the American National Metric Council.

To minimize costs and maximize the benefits associated with metrication, thoughtful and coordinated planning is essential.

Within the corporate policy and procedures framework, each business shall establish metrication objectives (soft conversion, hard conversion, rationalization, optimization) for its products and business practices, and outline a program for achievement. Manufacturing and support groups shall similarly establish metrication objectives and activities that directly support the business. Each manager shall incorporate metrication activity plans in his annual statement of goals and program and standards of performance and communicate them to the Corporate Metric Review Committee."

2.2 State Construction Related Metric Activities

The following construction related information concerning state metrication activity was extracted from the 1978, 1979, and 1980 Editions of the Metric Yearbook, published by J. J. Keller and Associates, Inc., 145 W. Wisconsin Avenue, Neenah, WI 54956. Also noted are those states with metric committees.

Arizona - has a Metric Advisory Committee and has passed legislation concerning the recording of land in metric measurements.

California - has a Metric Conversion Council to coordinate changeover to the metric system and to keep in step with the national effort. There is a licensed contractor on the Council. Two of the Council's major objectives are to encourage standardization, and to identify Federal, state, and local laws and codes requiring amendment for metric conversion.

Colorado - has a Metric Advisory Board.

Connecticut - has a Metric Coordinating Committee. The state is a member of the Northeast Metric Coordinating Council which is comprised of six New England states. In 1979, the State Legislative Research Committee was actively researching all the measurement sensitive portions of existing statutes so that proper legislation can be amended which will properly effect the change-over at one given time.

Delaware - All plans done in the Delaware Department of Transportation include metric equivalents.

Florida - has a Metric Council which has a construction subcommittee. A Florida Metric Plan was accepted by the Governor and Cabinet on November 21, 1978. One of the purposes of the planning effort stated in the Plan is "To insure that all legal and procedural barriers (federal, state, and local) to voluntary metric conversion are removed."

Indiana - Senate Bill 224 was introduced in the state legislature in 1979, and would have provided for a statewide referendum on mandatory adoption of the metric system in the United States. This bill met the same fate as other bills in this subject area--inaction for the remainder of the session.

Iowa - the Highway Division of the Iowa Department of Transportation has a metric task force concerned with conversion of the highway system, including signing, maintenance, stationing and construction contracts.

Maine - has a Governmental Metric Policies Committee.

Massachusetts - is a member of the New England Metric Coordinating Council and has established a Northeast Metric Resource Center at the University of Massachusetts.

Montana - has an Intergovernmental Metric Task Force.

Nebraska - a Nebraska Metric Board is currently in the process of forming, with representation from industry, agriculture and education.

Nevada - has a Nevada Metric Committee. The Nevada Department of Transportation established a timetable for completing a metric construction project, but the timetable is not being followed currently due to "the interruption in the metrication activities at the state and federal level," according to the metric coordinator for that Department.

New Hampshire - is a member of the New England Metric Coordinating Council.

New York - has a New York State Metric Council. The state enacted a law in 1977 to make the metric system the "preferred" system in the state, but allows use of customary units. In February 1978, Article 16 of the Agriculture and Markets Law (Weights and Measures Law) revision became effective. It reads in part: "The Legislature hereby finds and declares that voluntary and orderly conversion to the metric system of Weights and Measures is of vital importance to the economy of the state. It is hereby declared to be the public policy of this state to encourage the gradual implementation of the metric system throughout the state's government, industry, commerce, business, education, and agriculture." The New York State Metric Council conducted a study of state laws to determine how often customary measurement units appear therein.

North Carolina - has a Metric Planning Board.

North Dakota - as parts of the North Dakota Code are replaced, metric equivalents are inserted in the replacement sections. Future legislation is drafted with metric equivalencies inserted. In 1979, its legislature enacted Senate Concurrent Resolution No. 4010, urging the United States Congress not to pass any legislation mandating conversion to the metric system in the United States. This concurrent resolution passed the Senate on an unrecorded vote and passed the House by a vote of 46 to 45. A concurrent resolution is not legislation and thus does not require a constitutional majority to pass.

Ohio - the Ohio Department of Transportation prepared a report on highway metrication listing a five-phase experimental program which consisted of (I) Design of two metric highway projects; (II) Construction of these two projects; (III) Public Use and Adoption of Highway Signs; (IV) Public Information; (V) Public Reaction. In a speech the Ohio Department of Transportation Director stated, "...a true conversion to metric cannot be done at the local level...all industry would have to convert to have the U.S. become truly metric." In addition, he stated, "The primary cost of conversion would not be as expensive as originally conceived."

Oklahoma - in Oklahoma the metric system has been jointly recognized with the customary system for some time and can be used for any commercial purpose.

Oregon - the metric system has been jointly recognized with the customary system and can be used for commercial purposes. A project of the Oregon Department of Transportation involved design and preparation of contract documents utilizing the metric system for a highway improvement project. Two bridges have been completed using metric measurements.

In 1979, another metric construction project was completed successfully by the Oregon Department of Transportation. This small effort included replacing an antiquated bridge with a culvert.

In addition, a field survey has been completed on a metric bridge replacement project and it is now in the design stage. The Department of Transportation has also been involved in preparation of right-of-way documents for a metric highway improvement project.

South Carolina - has a Metric Advisory Committee.

Tennessee - has a Metric Conversion Committee.

Texas - has a Metric System Advisory Council. Two information surveys have been completed, one dealing with a computer search of Texas statutes for frequency of occurence of measurement units to determine how much adaptation would be necessary to effect metric conversion of existing statutes; and a survey of colleges and universities to determine whether they had metric courses in progress.

Vermont - has a Metric Coordinating Council. Its 1979 work plan included as a goal the preparation of a 10-year state plan for the conversion to Metrics for the State of Vermont and included actions appropriate for the executive and legislative branches of state government, as well as the Vermont Metric Coordinating Council. The Council has a subcommittee on Building and Construction.

Wyoming - According to a state bridge engineer in the Wyoming State Highway Department, "The only metric activity we have undertaken in 1979 is to include soft metric conversion in our "Specification for Road and

Bridge Construction" which will be published in 1980. We have shown the metric equivalents in parentheses after the U.S. units, and the metric equivalents are in accordance with ASTM E380-76."

PART 3 - TECHNICAL IMPLICATIONS OF METRIC CONVERSION IN THE CONSTRUCTION INDUSTRIES

3.1 General Aspects

What we loosely call "metric" is a comprehensive measurement system with a decimal base, derived from the metric system, which was developed in France during the last decade of the eighteenth century to replace a variety of non-standard "primitive" measures. The modern metric system —which is known as "SI," for the French term "Systeme International d'Unites"—is fixed by international agreements which include the U.S. as a signatory. SI includes units for every physical quantity. Metric usage has been legal in the United States since 1866, and all customary units used in the United States have been defined in terms of metric units since 1893. SI units are already widely used in some engineering disciplines, such as electrical engineering, illumination engineering, and acoustical engineering.

The American Society for Testing and Materials (ASTM) standard ASTM E380-79 [1] and the Institute of Electrical and Electronic Engineers (IEEE) Standard 268-1979 [2], both titled "Standard for Metric Practice," are recognized as key standards. Formerly, these two standards formed the basis for American National Standards Institute (ANSI) Z210.1, "American National Standard for Metric Practice." However, the 1979 editions differ marginally, so neither has been endorsed as an ANSI standard.

The construction community has its own supplementary standard to ASTM E380, ANSI/ASTM E621-78 [3], "Standard Practice for the Use of Metric (SI) Units in Building Design and Construction." This standard sets out rules and recommendations for the use of SI units in design and construction, discusses special considerations in the selection of units, provides tables of preferred and acceptable units for various discipline groups, including examples of typical applications, and contains a set of conversion factors for the most common units used.

The availability of these standards makes it possible to select correct SI units for data presented in metric units only, or in dual units, and enables values to be converted with an appropriate degree of precision.

The matter of selection of "preferred" metric values is addressed in detail in NBS Technical Note 990, "The Selection of Preferred Metric Values for Design and Construction" [4]. The Technical Note provides a rationale for preferred numerical values, gives guidance on conversion decisions, and includes a methodology for manual or automated conversion of values in standards and technical documents.

3.2 A Comparison of Features of SI and U.S. Customary Units

When appraising the merit of alternative measurement systems in practical use, especially in building design and construction applications, it is desirable to compare the features of the respective "systems." (See table 3-1.) In discussions to date, the debate seems to have remained in the scientific realm among supporters of SI, and in the popular domain among people opposed to change from U.S. customary units—with little exploration of common ground.

The metric system, despite its new and foreign names—even in France—was adopted by one country after another, not by force, but because of its intrinsic features in simplifying communications, specification, calculations, measurement, and control. The founders of the system had taken heed of their brief to develop a universal and permanent system, based on rational precepts. While the first objective was to replace the great diversity of measures then in use in France and Europe, both in nomenclature and magnitude of units with the same name, the features suggested in the 1790's included: coherence, decimalization, and the designation of absolute, reproducible standards, all of which have remained features of SI, the modern metric system.

From a construction industry viewpoint, the key features in SI are the reduction in the number of units of measurement, coherence (one-to-one relationships) between units, and the availability of decimal prefixes to select working units which preserve simple numerical values.

3.3 On Units and Numbers

To understand the implications of a measurement system, it is important to appreciate the role of units and numbers, because it is in this respect that SI and U.S. customary units differ most.

Any measuremment statement, or "numerical value," is a combination of a unit and a number; the unit represents the reference quantity but would make little sense on its own, while the number indicates the multiple of the reference quantity, and, again makes little sense on its own. (An exception occurs in tabulations or drawings, where a general statement of the reference quantity makes it possible to represent numerical values by a number only; e.g., all dimensions are in millimeters.)

U.S. customary units for length, capacity, and mass date from the middle ages, where an "additive system" of multiple units was used to indicate magnitudes; for example, a precise statement required pounds and ounces, or feet, inches, and fractions. (The additive system goes back to antiquity and is still in use in units for time [year, month, week, day, hour, minute, and second] and plane angle [degree, minute, and second of arc].)

While an additive system can be used to measure precisely, any mathematical operation which is performed on the "numbers," becomes complex,

Table 3-1: Concepts in Measurement: Comparison of SI and U.S. Customary Units

CONCEPTS	SI (METRIC) UNITS	U.S. CUSTOMARY UNITS
1. Completeness	SI has a unit for every physical quantity.	Multiple units exist for most physical quantities, but are supplemented by metric or SI units in many fields.
2. Uniqueness	SI has only one recognized unit for any one physical quantity. (For practical reasons, a number of non-SI units or multiples are accepted — units for time, angle, and multiples such as hectare, liter, metric ton.)	A variety of units exist for physical quantities, often for special applications only. For example, without counting superseded or special units, there are 9 units for length, 5 for mass, and 7 for volume or capacity.
3. Coherence	SI units are all coherent, that is, they have a one-to-one relationship to each other, based on their unit derivation according to the laws of physics.	Customary units have only limited coherence, and result in the introduction of factors other than 1, when changing from one unit to another; for example, 2,3,4,6,8, 9,12,16,20,22,24,27, etc.
4. Decimalization	SI uses standard decimal prefixes (powers of 10) to alter the magnitude of the reference quantity. These prefixes merely change the position of the decimal point, not the digits in a number. The prefixes are internationally used and understood.	Large or small values are transformed into a different, non-decimal unit, except for the mil (1/1000"), the square (100 ft^2), and the kip (1000 lbf). The ratio between units, or factor, alters the numerical values in calculations.
5. Unit Names	SI unit names, except for traditional metric names taken from Greek or Latin words, are derived from the names of great scientists, which are the same in all languages.	Customary units have names based on words in the English language. These words have no meaning in other languages. In some instances, the same name is used for different magnitudes.
6. Symbolization and Rules	SI units and prefixes are represented by internationally agreed letter symbols, which have the same meaning regardless of surrounding language or script. SI has agreed rules for the use of units, symbols, and numbers.	Unit names can be represented by symbols (ft, lb, qt), signs (", ', °), or abbreviations (fps, psi, cfm). Their use relates to the English language context only. There are few formal rules on unit use.
7. Reproducibility	SI units are scientifically defined to allow their accurate determination anywhere in the world, except for the kilogram which is based on an artifact.	U.S. customary units have been defined in terms of metric or SI units, e.g., 1 ft = 0.3048 m.
8. Universality	SI units are "international" and represent the official measurement system of most nations of the world. An international governing body (CGPM) maintains the system and its rules, including periodic review.	U.S. customary units represent a national measurement system, not used outside the United States.

even simple addition and subtraction. Multiplication and division is time consuming as all values have to be converted to the lowest common denominator (e.g., 4'-10" = 58") or else decimalized (e.g., 4'-10" = 4.833') before such operations are commenced, and then reconverted afterwards. Moreover, in division, the fractions available may not be sufficient to give a precise result, so that the parts differ. This "fudge factor" frequently occurs in stairs, where the division of floor-to-floor height (in feet and inches) into an equal height of riser (in inches and fractions) generally leaves a small residual fraction which is distributed over a number of risers.

From the start, metric measurement looked for a direct relationship to the decimal system of numbers. The first application of a decimal system, indeed, occurred in the United States where decimal currency was introduced some years before the metric system was conceived and finalized in France. Metric is "decimal," and the originators of the system even tried unsuccessfully to decimalize time and angular measurement.

From a productivity point of view, metric operations would be simpler, quicker, and less error-prone, because units follow the decimal number pattern by having decimal relationships only.

In all other nations that have changed to metric units, proponents and opponents have contrasted "a national metric system" and "a familiar customary system." People as well as computers work better with decimal units than with compound (additive) values, and this may explain why those groups whose work predominantly involves computations or measurement decision, such as building designers and engineers, have been supportive of an early change to SI. Increases in the productivity of design and documentation activities using metric units have been reported from other English-speaking countries.

3.4 Coherent Units

All units in SI are "coherent," that is, they relate to each other on a unity or one-to-one basis, without any factors or ratios as in the U.S. customary (or inch-pound) system. All units in SI are exclusively derived from seven base units representing fundamental physical quantities (length, mass, time, electric current, [thermodynamic] temperature, amount of [molecular] substance, and luminous intensity) and, in some cases, also from two supplementary units (plane angle and solid angle). Five of the nine units are already in use in the U.S. customary system. Derived units are formed by multiplication, division, or compounding of fundamental units, and some derived units have special names.

Part 6 provides practical applications of coherent units in energy design, but for the purposes of illustration, coherence can be understood better when the relationships of the already familiar unit for power and heat flow, the watt (W), are examined:

Electrical power:	$1\ W = 1\ V \cdot A$	(1 watt = 1 volt x 1 ampere)
Heat flow, energy, or work per unit time:	$1\ W = 1\ J/s$	(1 watt = 1 joule per second)
Work or energy per unit time:	$1\ W = 1\ N \cdot m/s$	(1 watt = 1 newton meter per second)
Expression in terms of SI base units:	$1\ W = 1\ kg \cdot m^2/s^3$	(1 watt = 1 kilogram meter squared per second cubed)

System coherence not only facilitates calculations, but simplifies comparisons; for example, the watt (W) would be used in SI for all forms of power and heat flow, thus allowing direct comparisons between alternatives or systems. The watt will remain where it is now used, and replace the following U.S. customary units: Btu/h, Btu/min, Btu/s, ft·lbf/h, ft·lbf/min, ft·lbf/s, horsepower (boiler), horsepower (electric), horsepower (550 ft·lbf/s), horsepower (water), and the ton (refrigeration).

3.5 Decimalization

The decimal number system, which uses the base ten, is in worldwide use, and its number symbols are understood regardless of language or surrounding script. Each symbol has an absolute value as well as a value of position, so that numbers can be written as a linear combination of powers of ten; for example:

123 456 [one hundred twenty-three thousand four hundred fifty-six] really means: $1 \times 10^5 + 2 \times 10^4 + 3 \times 10^3 + 4 \times 10^2 + 5 \times 10^1 + 6\ [\times 10^0]$.

Approximately 400 years ago, the concept of positioning was extended to include decimal fractions, using negative powers of ten to the right of a decimal marker, and this innovation made it possible to accurately express divisions, complex numbers, and all values smaller than one (1.0). It is no longer necessary to express fractions by means of a numerator and denominator, but as a decimalized value; for example, one sixteenth (1/16) becomes 0.0625, one tenth (1/10) becomes 0.1. The profound merit of decimalization of fractions was grasped very quickly and mathematics and physics advanced significantly; for example, making possible the expression of logarithms.

Decimal measurement systems were advocated as early as the 16th century to replace the variety of medieval measures then in use, but a spirit of revolution against outdated practices to bring about change was needed. The concept of decimal prefixes (words and symbols signifying the multiplication of a unit by a power of ten; for example: kilo (k) for 10^3, or milli (m) for 10^{-3}) provides simple numbers—instead of 2500 grams, 2.5 kilograms can be used; or in lieu of 0.010 meter, 10 millimeters can be used. Decimal prefixes (or factors) do not change the digits, only their position relative to the decimal point. The only factor that appears in metric calculations is ten (or a power of ten), and the unit name is retained, even though the prefix may be changed.

In building design activities, decimalization combined with coherent units greatly facilitates calculations and decision-making. The value of decimal units has also been recognized in U.S. customary measurement; wherein the mil represents one thousandth of an inch (0.001") and is used in precision measurement; the building square represents 100 square feet (ft^2); the kip represents 1000 pound-force (lbf), and the chain of feet, or 4 ~~rods,~~ has been divided into 100 links for ease of calculation.

3.6 Metric Practice - or, Rules for the Use of SI

In contrast to customary measurement which has no explicit book of rules for the selection and use of units, their presentation and symbolization, and numbers used in conjunction with units, SI is accompanied by an internationally agreed set of rules and recommendations to ensure consistency and to avoid misunderstandings. These rules are mostly commonsense prescriptions which, with a little practical application, are easily learned.

ANSI/ASTM Standard E621-78, deals with "rules and recommendations for the presentation of SI units and symbols" in table 5, and with the "presentation of numerical values with SI" in table 6.

A number of metric practice guides for specific disciplines has been prepared by professional societies or industry associations, as well as individual corporations. These are included in Part 9 of this report.

The surveying and mapping community has developed a comprehensive and thorough "Metric Practice Guide for Surveying and Mapping" [5], issued in March 1978 by the American Congress on Surveying and Mapping.

3.7 The Practical Application of Measurement

Measurement units are used in a number of different ways, from approximations to very precise measurements. The impact of metrication, correspondingly, would have different overtones.

3.7.1 Estimation of Magnitudes. Estimating magnitudes in terms of reference quantities is a "learned" aspect of measurement and principally involves memory and judgment. For example, if one hundred people are asked to estimate the length of a dollar bill, in inches, a normal distribution is likely to result, with some estimates stating a length that is far too short, and some far too long. Estimating temperature or speed is more difficult, and that of force, pressure, or power almost impossible without some form of measuring instrument. In estimating, we use "mental images" or recognition points, such as one's own height, reach, or fingerspan, and the main task in metrication would be to generate a new data bank of learned names, relationships, and magnitudes for meaningful assessment of physical factors. The need to "relearn" causes objection to change by some.

3.7.2 General Communication of Measurement Information. The communication of measurement data can involve either estimates or approximations, or highly precise measured data. For either communication, the receiver of the message must be in a position to assimilate and process the message in a meaningful way. For example, if temperatures are given in degrees Celsius (°C) only, an association between numerical value and sensation of comfort (cold, cool, mild, warm, hot) would soon be obtained. However, if both a familiar reference (in degrees Fahrenheit) and a metric reference (in degrees Celsius) are given, the unfamiliar value would be selectively blocked out with almost no long term memory. Where the precise communication of measurement information is essential to a task, such as calling out values obtained by measurement to a person who records them, it is essential that both the measurer and the recorder are fully familiar with the units and values that are used.

3.7.3 Descriptive Information in Written, Typed, or Printed Data. Descriptive information in "software," such as standards, technical data sheets, textbooks, drawings, and the like, requires compactness, lack of ambiquity, and consistency in presentation. In most instances, metric data would be advantageous.

The largest part of initial activity in metric conversion would involve software, to be prepared either in metric units only, or in dual units for the duration of a transitional period. Metric practice information would be needed to allow people in the construction community to assimilate metric task information.

3.7.4 Calculations and Computation. As already indicated, metric measurement was designed for greater productivity in all mathematical processes involving measurement decisions. The concepts of unique units, coherence, and decimalization combine to give greater speed and fewer errors. Engineering calculations, in particular, would benefit. Architectual documentation, with only one measurement unit for length--the millimeter (mm)--would be simplified significantly, and check-outs for accuracy facilitated.

3.7.5 Practical Measurement in Production and Construction. To measure magnitudes of physical quantities such as thickness, mass, thermal properties, electrical properties, etc., any measurement system will suffice. However, if comparisons are to be made with international standards, or requirements set out in metric terms, the use of metric measuring devices would be preferable, rather than the use of non-metric devices and subsequent conversion.

Precision in measurement is a function of the following: accuracy of the measuring instrument, accuracy of the operator (reader) and/or transcriber, and the graduation of the instrument. For example, with a measuring tape graduated in inches only, measurements can be made to the nearest whole inch, while smaller intervals have to be interpolated by judgment. Normal steel tapes for construction measurement are graduated in multiples of 1/16", so that measurement can be laid out or read to the nearest 1/16". Similarly, metric construction tapes are graduated in millimeters, so that measurement can be effected to the nearest millimeter (mm). The metric graduation will encourage more precise measurement and would be likely to lead to fewer deviations in additive measurement during production, layout, or construction. Conversely, temperature readings can be made with greater precision on the Fahrenheit (°F) scale than on the Celsius scale (°C), due to the finer graduation of the Fahrenheit scale.

In production and construction measurement, the use of metric units could generally increase measurement precision.

3.7.6 Quality Control, Testing, and Research. Quality control in production requires precise measurement to ensure that product characteristics remain within specified limits; that is, fall within permissible tolerances. In general, the use of millimeters for the measurement of length, width, depth, thickness, diameter or radius, warping or twisting, and squareness would facilitate quality control operations.

A high percentage of testing and laboratory work in product manufacture already is carried out in metric units.

3.8 Metric Units for Use by Tradesmen and Site Personnel

Considerable attention has been paid to metric (SI) units for building designers and other professional groups. However, most practical tasks for measurement in production and construction are carried out by skilled and unskilled workers, to whom the change of measurement units may be a cause for some concern.

In the construction environment, the number of units required to be used will reduce, so that the learning situation is not as great as imagined at first sight. Precedent has indicated that there is little merit in "overtraining" personnel, especially in aspects of the metric system that will never be applied in practical use. For most tradesmen and on-site personnel, training on the job is the best approach as it puts metric concepts into a practical perspective.

Table 3-2 shows the most common metric units that would be used in various construction-related activities.

Table 3-2: Key Metric Units for Use on the Job

ACTIVITY	QUANTITY	UNIT(S)	SYMBOL(S)
BLOCK AND BRICK MASONRY	Linear Measurement Area Volume (of mortar) Mass (weight)	millimeter, meter square meter cubic meter kilogram	mm, m m^2 m^3 kg
CARPENTRY	Linear Measurement Area	millimeter, meter square meter	mm, m m^2
CONCRETE WORK	Linear Measurement Area Volume Temperature (of ingredients) Mass (weight) (of ingredients) Capacity (water) Cross-section (of reinforcement)	millimeter, meter square meter cubic meter degree Celsius metric ton (1000 kg) liter square millimeter	mm, m m^2 m^3 °C t L mm^2
ELECTRICAL SERVICES *already in common use	Linear Measurement Frequency Power Energy Electric Current Electric Potential Electric Resistance	millimeter, meter *hertz, kilohertz *watt, kilowatt megajoule, *kilowatthour (3.6 MJ) *ampere *volt, kilovolt *ohm, kilohm	mm, m Hz, kHz W, kW MJ, kWh A V, kV Ω, kΩ
EXCAVATING	Linear Measurement Volume Mass (weight)	meter cubic meter metric ton (1000 kg)	m m^3 t
GLAZING	Linear Measurement Area Mass (weight)	millimeter, meter square meter kilogram	mm, m m^2 kg
LAND SURVEYING	Linear Measurement Area	meter, kilometer square meter, hectare (10 000 m), square kilometer	m, km m^2, ha km^2
MECHANICAL SERVICES	Linear Measurement Volume Capacity Airflow (Velocity) Volume Rate of Flow Temperature Force Pressure, Stress Energy, Work	millimeter, meter cubic meter liter (1 m = 1000 L) meter per second cubic meter per second, liter per second degree Celsius newton, kilonewton kilopascal, magapascal kilojoule, megajoule	mm, m m^3 L m/s m^3/s L/s °C N, kN kPa, MPa kJ, MJ
PAINTING	Linear Measurement Area Capacity (of paint)	meter, millimeter square meter liter, milliliter	m, mm m^2 L, mL
PAVING, PLASTERING, TILE LAYING	Linear Measurement Area	millimeter, meter square meter	mm, m m^2
PLUMBING (See also: Mechanical Services)	Linear Measurement Capacity Mass (weight) Pressure	meter, millimeter liter kilogram, gram kilopascal	m, mm L kg, g kPa
ROOFING	Linear Measurement Area Slope	millimeter, meter square meter millimeter per meter (or use numerical ratio)	mm, m m^2 mm/m
SEWAGE DISPOSAL, SITE DRAINAGE	Linear Measurement Area Volume Capacity Slope	meter, millimeter square meter, hectare (10 000 m) cubic meter liter millimeter per meter (or use numerical ratio)	m, mm m^2, ha m^3 L mm/m
STEELWORK	Linear Measurement Mass (weight)	millimeter, meter metric ton (1000 kg), kilogram	mm, m t, kg
TRUCKING	Distance Volume Mass (weight)	kilometer cubic meter metric ton (1000 kg), kilogram	km m^2 t, kg

3.9 Metric Measuring Instruments

One of the real costs of metric conversion is the purchase of metric measuring instruments, such as drafting scales, steel tapes, weighing devices (scales), gauges and dials, levels with graduations or markings, micrometers, test sieves, and some specialized items for quality control or performance measurement. The cost of procurement can only be reduced if normal replacement cycles are used to acquire metric rather than customary instruments. In some instances, it would be more practical to effect a partial replacement; for example, the purchase of a blade with metric graduations for a steel tape rather than purchasing the entire new unit, or a metric dial for a pressure gauge rather than a new gauge.

Although not preferred in the long run, tapes, scales, and gages may be obtained with a dual readout for use in a transitional period; for example, steel tapes are commercially available now with graduations both in inches and fractions on one edge of the blade, and graduations in millimeters on the other.

Special care should be exercised in purchasing decisions to make sure that the "metric" instruments feature correct units and standard graduations. For example, tapes graduated in centimeters (cm) are widely sold for general use, while the construction community probably would use millimeters (mm); the purchase of the wrong measuring devices could create confusion rather than simplification. Similarly, a variety of gages imported from traditionally metric countries are calibrated in non-SI units, such as the bar, millibar, atm (standard atmospheres), kgf/cm^2, etc., rather than in pascals (Pa) or kilopascals (kPa). Uninformed purchasing could cause confusion, apart from waste of money.

At this time there are no national standards that outline preferences for metric drafting scales, steel tapes, surveying instruments, mass scales and other weighing devices, thermometers, pressure gages, etc., and it appears that the industry would benefit from standardization efforts. ASTM Standard E11-70 (Reapproved in 1977) [6], dealing with test sieves, does list metric sieve designations as standard sizes corresponding to those recommended by ISO, and also includes alternative designations.

A number of American multi-national corporations produce preferred metric measuring instruments in other countries and are well equipped to serve the needs of the U.S. construction community during a transition to metric measurement.

3.10 Metric Standards

The Metric Conversion Act of 1975 specifically addresses the subject of metric standards and states in Section 6:

..."In carrying out this program, the [United States Metric] Board shall—(4) encourage activities of standardization organizations to develop or revise, as rapidly as practicable, engineering standards on a metric measurement basis, and to take advantage of opportunities to promote (A) rationalization or simplification of relationships, (B) improvements of design, (C) reduction of size variations, (D) increases in economy, and (E) where feasible, the efficient use of energy and the conservation of natural resources;"

Most of the voluntary national standards-writing organizations in the United States have policies to use or include metric (SI) units in their standards, although not necessarily as "hard-converted" and preferred values. Where available, the policy decisions of relevant building design and construction standards-writing organizations are given in Part 2.

3.11 Metric Building Codes

There are no fully metric building codes or model codes available in the United States although some major code-developing organizations have decided to include metric equivalents in future editions. There are a number of options, ranging from the use of dual measurement units (with varying degrees of rounding and rationalization), to the preparation of dual documents with separate, preferred values for use with each measurement system. The latter approach would provide the most convenient numbers for designers, manufacturers, contractors, and building controllers but is likely to require considerable investigation and inter-industry discussion to arrive at preferred values.

3.12 Technical Reference Material, Handbooks, and Textbooks

At present, technical information for professional and other personnel in the construction community is predominantly in U.S. customary units, although some professional institutes and societies are rapidly developing a metric data base. Scientific handbooks and college physics texts are largely in metric units, although they do not always adhere to correct SI units and presentation.

The American Institute of Architects, in conjunction with Wiley Interscience, has prepared the "AIA Metric Building and Construction Guide" [7], a comprehensive and thorough basic reference document for building designers and others interested in the application of SI in construction.

A number of engineering textbooks dealing with the change to metric (SI) units have been published. "Metric Units in Engineering—Going SI," by Professor Cornelius Wandmacher [8] provides a useful and comprehensive general text to acquaint engineers and engineering students with the concepts, relationships, and practical application of SI.

A comprehensive metric bibliography is provided in Part 9.

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5. Metric Practice Guide for Surveying and Mapping; American Congress on Surveying and Mapping, Falls Church, VA; March 1978; 12 pages.

6. Wire-Cloth Sieves for Testing Purposes, ASTM E11-70 (reapprovved 1977), American Society for Testing and Materials, Philadelphia, PA; 1970; 5 pages.

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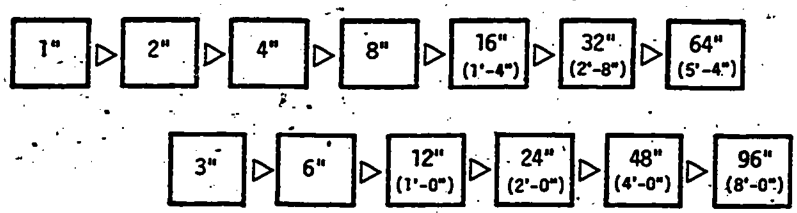
PART 4 - METRIC CONVERSION AND DIMENSIONAL COORDINATION IN BUILDING

4.1 Dimensional Coordination: Background

In an industry where most tasks involve dimensional control of products, components, assemblies, and building elements, as well as their combination and fitting to form buildings and structures, dimensional standardization is an essential ingredient of cost-effective operations. The alternative of random sizes would involve extensive cutting or make-up activity, and result in waste of materials as well as low productivity. Dimensional coordination simply is a rational approach to the determination and selection of preferred sizes for building products, and of preferred dimensions for spans and spaces, based on a common denominator, the "building module" or basic unit of size. For this reason, it is also referred to as "modular coordination."

In historical building activity, many components were custom made or shaped, or produced in small quantities, so that special sizes carried no significant cost premium. A concept of preferences emerged, based on whole multiples of the customary units of measurement, the foot and the inch. Most preferred among these values were those that formed a simple doubling series, for example:



These ranges are related by a factor of three, so that any size of the inch-based series, when trebled, equals a value in the foot-based series. Examples of customary product sizes from these two ranges abound, and include brick, block, floor and ceiling tile, panels, planks, and many assemblies. In addition, multiples of selected dimensions were used for functional sizes and spaces in buildings, for instance whole multiples of the foot--2' (24"), 3' (36"), 4' (48"), and 5' (60")--as planning modules. This system works quite well, except for the occasional mismatch in dimensions which is sorted out by design detailing or construction fitting on-site. Some minor inconvenience was caused by having to work with essentially three measurement units: feet, inches, and common fractions of inches.

With increasing industrialization of the 20th century, proposals emerged in the 1920's and 1930's for a comprehensive and rationalized approach to design and construction dimensions, and related building product sizes. The best known pioneering work was done by the American industrialist Albert Farwell Bemis (1870-1936), who proposed a 4-inch module as basic unit of size for buildings as well as building components, and who developed a comprehensive approach to coordination, subsequently referred to as "modular coordination." The 4-inch unit of size was given the symbol M (for module), and whole multiples of M were preferred for all dimensions. The system also included a modular grid, with a 4-inch grid interval, for the precoordination and positioning of building elements and components. After Bemis' untimely death, his ideas became the basis for a national standards effort in "the coordination of dimensions in building," and a series of national standards became available after 1945. Masonry units, such as clay brick, concrete block, and clay flue linings were in the forefront of the change to modular dimensions based on the 4-inch module.

4.2 Metric Dimensional Coordination and the International Building Module

The ideas of modular coordination were picked up in post-World War II Europe, and they became the basis of the industrialized reconstruction program in a gigantic demonstration of how greater productivity can be achieved by the use of standardized dimensions rather than random choices. European nations used a 100 mm (10 cm) building module and found this basic and decimal unit to be of a near-optimum size to reduce variety while simultaneously retaining simplicity of numbers. The European efforts, in both Western and Eastern European countries were followed by extensive adoption of the principles in South and Central America and Asian metric countries. Subsequently, the 100 mm module was used as the basis of international (ISO) standards, prepared within the ISO Technical Committee 59, Building Construction, which was 52 member nations and 32 actively participating in the work. The international building module was given further emphasis when all English-speaking countries that changed to metric in the 1960's and 1970's adopted this module and selected mutliples in the determination of their dimensional preferences in building [1].

4.3 Metrication and Dimensional Coordination

Although a separate issue from metrication, dimensional coordination in the construction industry becomes like a Siamese twin: without at least a partial adoption of modular and preferred sizes during the change, one of the greatest opportunities of metrication in construction would be missed. In the United States, this fact is already widely appreciated, and both the U.S. Metric Study in 1970-71, and the GAO Metric Study in 1976-78 found support for this proposition, even though a considerable percentage of respondents did not give a definitive reply.

Question 14.h in the GAO Report, CED-78-128 [2], as part of a question dealing with "advantages frequently attributed to conversion with the metric system," stated:

> "Conversion will provide an opportunity for implementing or expanding 'dimensional or modular coordination'," defined in footnote three as "A direct relationship between the dimensions selected for

the design of a building and the sizes of components used in its construction. Product sizes and dimensions are based on agreed-upon rules that permit a better fit of products during the building process. Dimensions and sizes are based on a module, such as 4 inches or 100 millimeters."

Four response categories were used in Question 14: 1. Agree; 2. Disagree; 3. Does not apply; and, 4. No basis to judge. The following percentage responses are shown on page 16-27, of the report.

Group of Respondents	Overall Responses: Agree	Disagree	Does not apply	No basis to judge
All Associations	38%	13%	7%	42%
Designers	39%	12%	15%	33%
Contractors	44%	7%	9%	41%
Labor	44%	11%	--	44%
Manufacturers	32%	18%	8%	43%
Distributors	42%	5%	--	53%
Codes & Standards	60%	--	--	40%
Real Estate	22%	11%	6%	61%

It is interesting to note that, if one considers only the definite responses "agree" or "disagree," nearly three-quarters (74.5 percent) of all associations concurred with the question asked, ranging from 64 percent of manufacturers to 100 percent of codes and standards. However, it is also significant that almost half of the respondents (49 percent) selected the neutral choices "does not apply" or "no basis to judge." In the latter category the range is from 33 percent of designers to 61 percent of real estate.

All in all, the definite responses to the GAO Study reinforce the previous findings and statements by many leaders of the construction community that "metrication would be an opportunity for implementing or expanding dimensional or modular coordination in building."

4.4 The Metric Building Module Compared with the Traditional 4-Inch Module

The advantages of metric dimensional coordination in building are derived to a large extent from the mathematical and technical features of the metric building module of 100 mm, which represents one decimal part of the meter. This dimension is only 1/16" (or 1.6 mm) smaller than the traditional 4-inch module, which has been widely used in the sizing of building products and design approaches in the U.S. construction industry. Therefore, metric modular dimensions and sizes would differ only slightly—they would be 1.6 percent smaller and, in many instances, remain within existing tolerances. The principal advantages of the metric module are outlined below.

4.4.1 Metric Modular Dimensions are Directly Visible. Any dimension, in millimeters, with two zeros (00) at the end is always a modular dimension, that is, a whole multiple of the 100 mm module. But much more significant in the design and construction context, is that the "modular multiplier" is directly visible and represented by the number in front of the two zeros. This makes it possible to identify and select "preferred" multimodular values at a glance. For example, although 4700 mm is a modular dimension it can be recognized instantly as a less preferred multiple because the multiplier, 47, is a prime number and divisible only by itself and one. By comparison, 4800 mm, or 48 modules, has superior properties of divisibility—it is a whole multiple of the following "modular dimensions:" 2400, 1600, 1200, 800, 600, 400, 300, and 200 mm. Thus, when a choice is available, the designer and contractor would almost invariably be better off with 4800 mm.

In the customary context, multimodular dimensions are partly "hidden" by the need to use both feet and inches in stating them. For example, a dimension of 15'-8" can readily be recognized as a "modular" dimension, that is, divisible by 4 inches, but after a little mental arithmetic it becomes clear that the multiplier is a less preferred 47!

In another example, the foot-inch equivalent of 64 modules is 21'-4", which is not immediately recognizable as a whole multiple of 8" and 16", so common in standard product sizes and spacing of structural members. Quite a few designers, without thinking, might prefer 21'-0" or 22'-0" for building spaces or spans. There would be no such difficulty with 6400 mm, the equivalent of 64 metric modules, which can immediately be distinguished for its divisibility by 3200, 1600, 800, 400, and 200 mm!

4.4.2 The Modular Square—A Useful Aid in Calculations. The modular square of 100 mm x 100 mm, which provides the basic two-dimensional grid, has an area of exactly 0.01 m^2 (one hundredth of a square meter). This relationship is very useful in all forms of calculations involving area, such as in functional properties (structural, thermal, acoustic, etc.). A "modular" area in metric units simply is the product of the two multipliers; for example, a door of 800 mm x 2200 mm has an area of 176 modular squares (8 x 22), which can be converted directly to square meters by dividing by 100, so that it would represent an area of 1.76 m^2. If the door had been 2000 mm (or 20 modules) high, the calculation could have been done in the mind. By comparison, a modular square with 4" sides represents 1/9th of a square foot or 1/81st of a square yard, so that calculations are much more awkward. A customary door of 2'-8" x 7'-4", which has 176 customary modular squares, requires a lengthy calculation and rounding to establish its area, because there are no decimal relationships.

The direct relationship between the metric modular square and the square meter (m^2) becomes even more significant in calculating costs of buildings, building elements, or building components, where any cost in $/$m^2$ has the same numerical value in cents per square module. For example, a cost of $6/$m^2$ also represents a cost of 6¢ per square module. This enables more accurate costing of modular buildings and modular building products, as well as tighter cost control. In computerized building design and documentation, the cost of design alternatives could be factored into the decision process without much difficulty as part of metric modular coordination.

4.4.3 <u>The Modular Cube</u>. The modular cube of 100 mm x 100 mm x 100 mm, which is the basic unit in a three-dimensional modular space grid, represents a volume of exactly 0.001 m^3 (one thousandth of a cubic meter) and a capcity of 1 L (one liter). This relationship greatly simplifies all calculations involving volume or capacity, such as room or building volumes, cut and fill computations, HVAC design, and load estimates based on mass per unit volume of materials. The capacity as well as mass of the contents of rectangular storage tanks with modular dimensions can be calculated with ease, based on direct unit relationships that can be traced right back to the original concepts of the metric system of the 1790's. The units of volume, capacity, and mass were related on a one-to-one basis in the following sequence: 1 cubic decimeter (now a cubic module, as well) equals 1 liter, 1 liter of water at its maximum density has a mass of 1 kilogram. This relationship is still very useful; for example, if the specific gravity of a material is known, the numerical value also indicates the mass of a modular cube of that material. In unreinforced concrete with a specific gravity of 2.3 (or a mass density of 2300 kg/m^3) a modular cube would have a mass of 2.3 kg; in steel, with a specific gravity of 7.85 (mass density of 7850 kg/m^3) it would be 7.85; etc.

4.4.4 <u>An Example of Calculations with Modular Dimensions</u>. A practical example will illustrate the advantages of these relationships in a metric modular concept. A reinforced, precast concrete panel of 100 mm thickness, 1200 mm width, and 3200 mm height, with a specific gravity of 2.4 would have the following dimensional and related properties:

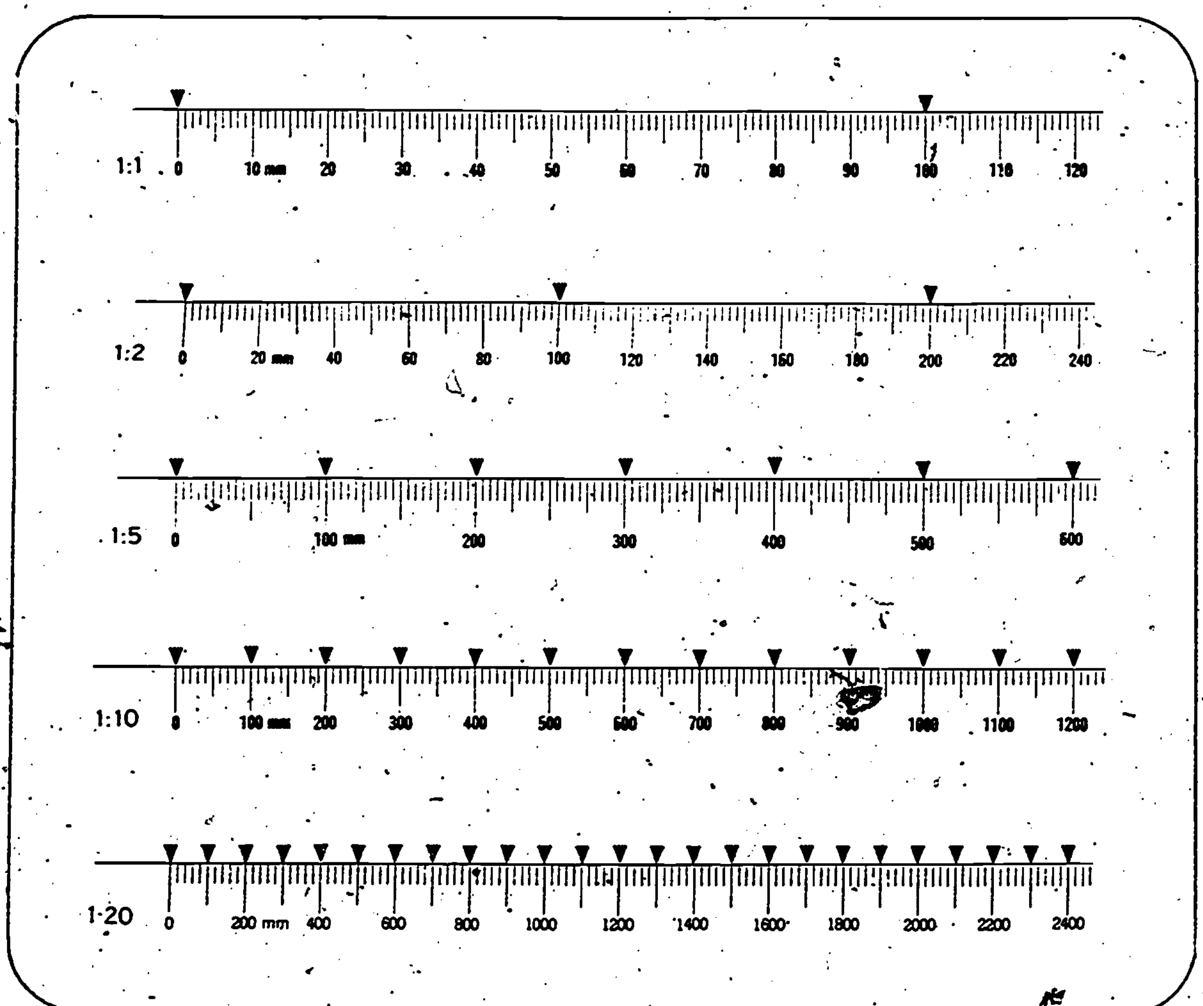
Area: 12[00] x 32[00] = 384 square modules = 3.84 m^2
Volume: 1[00] x 12[00] x 32[00] = 384 cubic modules = 0.384 m^3
Mass: 1 x 12 x 32 x 2.4 = 921.6 kg
Force: [mass x 9.8 m/s^2] = 921.6 x 9.8 = 9032 N = 9.032 kN

Thus area can be computed easily for functional properties or costing; volume for quantity of concrete required; mass for transportation of the panel; and force for lifting and structural load calculations.

4.4.5 <u>Metric Drawing Scales and the Building Module</u>. Because of the decimal relationships that extend right through metric measurement applications, the 100 mm building module has two other major advantages in measurement: it is represented directly as a scalar division on all drawing scales from 1:1 (full size) to 1:100; and it represents a major, marked graduation on construction tapes.

The scale instruments (hand scales or machine scales) prominently identify 100 mm and its multiples for ratios from 1:1 to 1:10, as shown in figure 4-1, and show a major graduation line for 100 mm on the 1:20 scale, where every multiple of 200 mm is marked. At scales of 1:50 and 1:100, the 100 mm building module is represented by 2 mm and 1 mm, respectively. Therefore, the designer working on detail drawings is constantly reminded of the "modular" dimension as a preferred value. This is not so in customary scales, which emphasize the foot (3 modules) and often the 6" and 3" subdivision, rather than the 4-inch module.

Figure 4-1: Examples of Drawing Scales with Modular Dimensions Emphasized



▼ The triangles have been added to point to locations of whole multiples of the 100 mm module on detail scales. They give a direct indication of the scale factor and the subdivision of the scale; for example; each mm represents an increment of 1 mm at 1:1; 2 mm at 1:2; 5 mm at 1:5; 10 mm at 1:10; and 20 mm at 1:20.

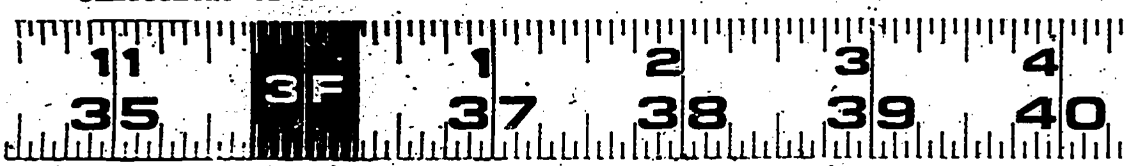
Construction steel tapes for use in building layout and measurement of building products are the principal measuring instruments on-site. U.S. customary tapes are graduated in feet, inches, and fractions. Many tapes also show a special marking for all multiples of 16 inches to facilitate layout at 16 inch centers. However, modular increments of 4 inches are not marked in any special way, except for multiples of three modules (12" or 1') and four modules (16") on some tapes.

Metric construction tapes are graduated in millimeters for short tapes, and meters and millimeters for longer tapes. Major graduations occur every 100 mm (or 0.1 m), thus emphasizing the metric building module at every increment. Other numbered graduation marks occur every 10 mm. These tapes greatly facilitate modular building layout on-site.

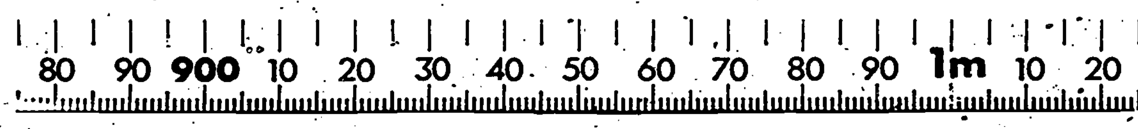
Sections of customary (foot-inch) tapes and metric (meter-millimeter) tapes are shown in figure 4-2.

Figure 4-2: Customary (Foot-Inch) and Metric Construction Steel Tapes

a. Section of 12-ft pocket steel tape graduated in feet, inches, and sixteenths of an inch



b. Section of 3 m pocket steel tape graduated in meters and millimeters (100, 10, 5 and 1)



c. Section of 30 m precision steel tape graduated in meters and millimeters

4.4.6 Endorsement of the 100 mm Metric Building Module. The 100 mm metric building module has been endorsed in publications or information released by major industry organizations in the United States such as:

- The American Society for Testing and Materials (ASTM)
- The American Institute of Architects (AIA)

The ANMC Construction Industries Coordinating Committee (ANMC/CICC) and its Sector Committees
The National Association of Home Builders (NAHB)

In addition, as outlined in Part 2, a number of major associations or societies have developed metric policy statements or guidelines which recommend the conversion to preferred metric dimensions and sizes--a hard conversion--rather than the use of metric equivalents for customary dimensions or sizes--a soft conversion.

4.5 The Practical Application of Dimensional Coordination in Building

Dimensional coordination in building represents a voluntary, but conscious attempt to "rationalize" the dimensions of buildings as well as the related sizes of building products or components through the use of a common unit of size--or module--and selected multiples. Like metrication, dimensional coordination is a matter for cooperative effort rather than mandate. The establishment of a successful program requires the cooperation of designers, manufacturers, and many other parties to the building process, to set down general rules and conventions for the use of preferred dimensions, including guidelines for joints, tolerances, and limits of fit.

Basically, there are few differences in the stated "aims, principles, or practical application" of dimensional coordination based on a 4-inch module, and dimensional coordination based on a 100 mm module. In the latter case, international recommendations and guidelines have been established, but the resulting conventions could be used with either module.

Recent trends worldwide indicate overwhelming support for the 100 mm module and the derived sizes, and many of the developing nations have chosen to adopt the content of ISO standards, in full or with minor variations, as their national standards. The trends also show a move away from the rigid application of modular grids as the basis for coordination, and the substitution of a few major "controlling planes or lines" instead. The distances between such controlling planes are called "controlling dimensions," and these are normally selected from preferred multiples of the building module.

On plan, such controlling dimensions can occur in two ways. They may either be taken between the "coordinating (or nominal) faces" of building elements, in which case they are referred to as boundary controlling planes, or they may be taken from axis to axis of structural elements, in which case they are referred to as axial controlling planes. Either approach has advantages. Normally, boundary control is more useful in buildings with many structural elements and subdivision into small spaces, for example in most residential type structures. Axial control, generally, is more appropriate in larger buildings or structures, with long spans and open plans, such as industrial type structures.

The alternative approaches are illustrated graphically in figures 4-3 and 4-4.

Figure 4-3: Boundary Controlling Planes

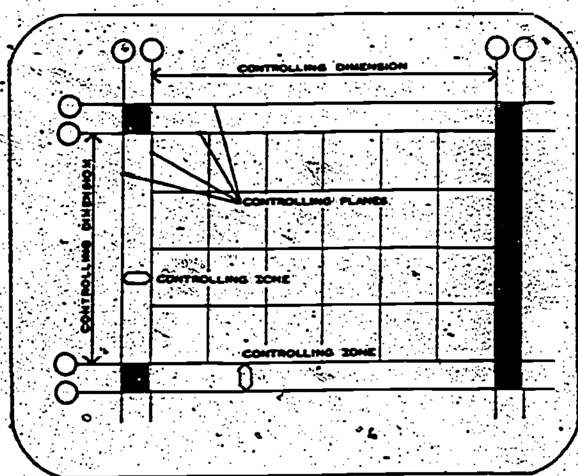
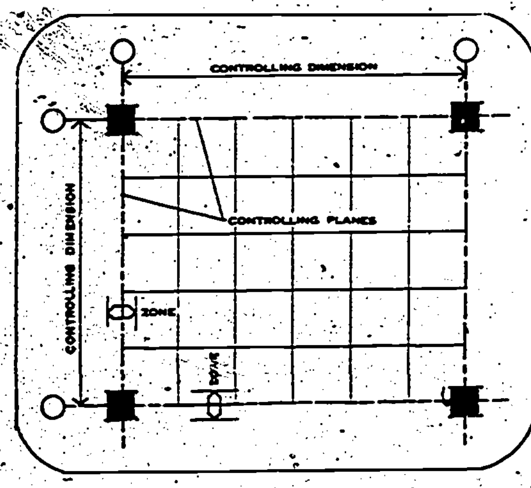


Figure 4-4: Axial Controlling Planes



Preferred dimensions for horizontal control have been established in ISO standards, and dimensions which are whole multiples of 300 mm, 600 mm, 1200 mm, 3000 mm, and 6000 mm are most favored, with a limited application of 1500 mm as an additional preference. The absence of U.S. representation in ISO has meant that the typical U.S. preference for four modules (or 400 mm) traditionally used in spans, spacings, and many product sizes (16" increments) is not included, except in the multiples 1200 mm and 6000 mm.

In section, controlling dimensions occur betwee controlling planes at floor level, ceiling level, and roof level. The, are generally referred to as floor-to-floor height (story height), floor-to-ceiling height (room height), ceiling-to-roof height, or floor-to-roof height, as appropriate. Multiples of 100 mm, 300 mm, and 600 mm have been suggested as preferred dimensions for vertical control in international proposals, with the use of such increments specified for particular ranges of dimensions. The typical U.S. preference for two modules (or 200 mm) traditionally used in masonry products (8" vertical control), is not specifically mentioned.

Additional intermediate controlling planes occur at door head and window head height, and at window sill level. These dimensions identify the vertical component of preferred opening sizes.

Vertical controlling dimensions and intermediate controlling planes are shown in figures 4-5 and 4-6.

Figure 4-5: Vertical Controlling Dimensions

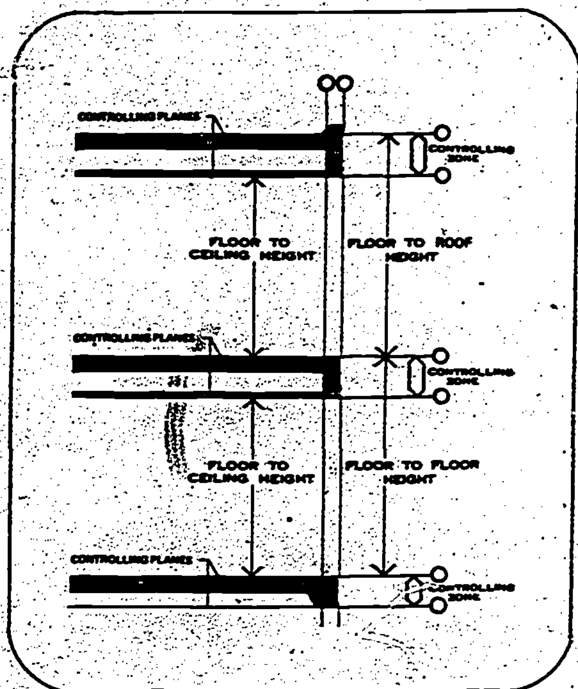
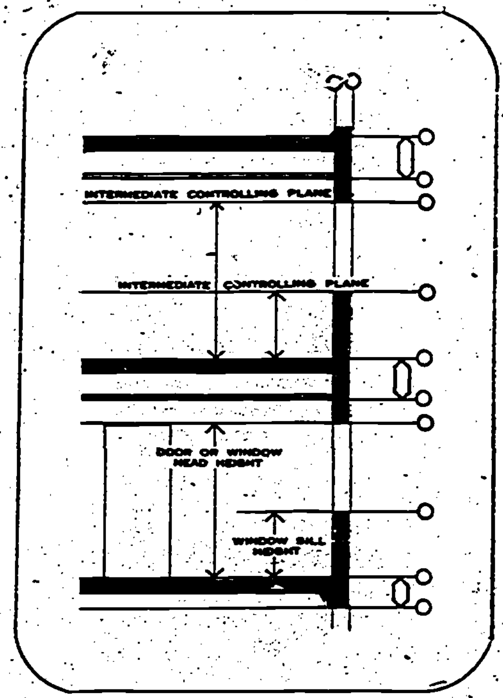


Figure 4-6: Intermediate Controlling Planes



A further refinement is the designation of supplementary spaces, or "zones," to accommodate structural elements and non-usable space. These zones may be modular (controlling zones) or non-modular (neutral zones).

4.6 The Choice of Preferred Dimensions

The principal aspect of dimensional coordination in building is the selection, by industry consensus, of "preferred" dimensions for the design coordination of buildings, and the sizing of building products. With careful choices and cooperation between all major groups affected, much greater "dimensional harmony" is feasible than is known today—without any sacrifice of flexibility. Customary sizes were developed in response to needs at particular points in time either unilaterally or by consensus. Many traditional product sizes are compatible with modular coordination, and the similarity in customary and metric modules should make it possible to continue production in the same facility and with the same equipment, albeit modified in some instances.

What then are preferred dimensions? As construction is an additive process, any dimension which can be further divided into whole modular subunits is definitely preferred. This is where multipliers such as 6 (divisible by 1, 2, and 3); 12 (divisible by 1, 2, 3, 4, and 6); and 60 (divisible by 1, 2, 3, 4, 5, 6, 10, 12, 15, 20, and 30) have decided advantages. In a metric modular context, dimensions such as 600 mm (6 modules), 1200 mm (12 modules), and 6000 mm (60 modules) have long been recognized as preferences, independently of their close similarity to customary dimensions of 2 feet (6 modules), 4 feet (12 modules), and 20 feet (60 modules).

In fact, metric preferences combine the benefits of decimalization, in the form of a 100 mm basic module, with highly divisible numbers, and, therefore, would provide some additional benefits. This is easily illustrated by a comparison of the customary modular dimension of four feet (equal to 48 inches, or 12 modules) and the metric counterpart of 1200 mm (12 metric modules). Table 4-1 lists divisibility into whole subunits, in modular as well as non-modular sizes. "Modular divisibility" remains the same, while non-modular divisibility is increased significantly. The non-modular sizes can be used for small additive components, such as tile, brick, etc., which are used in combination, for example, in mosaic patterns.

Table 4-1: Comparison of Divisibility

Divisor	4'-0" [12 modules]		1200 mm [12 modules]	
	Modular Size	Non-modular Size	Modular Size	Non-modular Size
1	4'-0"		1200 mm	
2	2'-0"		600 mm	
3	1'-4"		400 mm	
4	1'-0"		300 mm	
5				240 mm
6	8"		200 mm	
8		6"		150 mm
10				120 mm
12	4"		100 mm	
15				80 mm
16		3"		75 mm
20				60 mm
24		2"*		50 mm*
25				48 mm
32		1½"		
40				30 mm
48		1"*		25 mm*
50				24 mm
Total	6	5	6	12

* indicates a submodule

Similar comparisons may be made for each "pair" of customary and metric modules.

4.7 Issues in Production - Sizes of Modular Building Products and Components

The manufacturing industry is unlikely to produce metric modular products until a demand emerges. Such a demand is unlikely to develop before a construction industry M-Day, and may only build up slowly after that, as contracts for metric buildings are let. Initially, some metric modular products are likely to enter the market as additional product lines, but a prolonged transition period would probably create more problems for the manufacturer than the customer as a result of dual inventories. For this reason it is essential that "consensus decisions" be reached throughout industry--without a commitment the safest course might be to remain with traditional sizes and to let others hazard "metric experiments."

The lessons from other countries do not bear out predictions of gloom. They are particularly interesting in a logical approach to the establishment of "industry preferences" for building component and assembly sizes, based on the 100 mm module and selected multiples.

A "metric preferred size selection matrix" is shown in table 4-2. The purpose of the matrix, which was also included on page 54 of the AIA Metric Building and Construction Guide [3], is to facilitate the identification of size preferences in four product categories, ranging from small components to very large components.

In the sizing of modular products, it must be remembered that "coordinating dimensions" are ideal dimensions, taken from centerline to centerline of adjacent components; that is, they include half a joint width on each side. For example, the standard (or specified) size for modular masonry units with coordinating dimensions of 100 x 100 x 300 mm, would be one joint width less, or 90 x 90 x 290 mm for the standard 10 mm mortar joint. This is the same as in traditional practice, where a modular masonry unit of 4" x 4" x 12" with a 3/8" joint would have standard dimensions of 3-5/8" x 3-5/8" x 11-5/8", except that whole millimeters are used instead of inches and fractions. Similarly, in the case of building board or wallboard, the joint width is normally considered minimal and part of the tolerances allowed for production irregularities, so that a "coordinating size" of 1200 x 2400 mm (or the customary 4'-0" x 8'-0") would also be the standard (or specified) size.

Tolerances for metric product sizes will be expressed in millimeters rather than in fractional units; for example, a ceiling tile might be shown as 300 x 600 mm, with tolerances of -2 mm, +1 mm, compared with a customary ceiling tile of 12" x 24", with tolerances of -1/8", +1/16". (These values are shown only for illustrative purposes.)

Table 4-2: Metric Preferred Size Selection Matrix

CATEGORY	TYPICAL EXAMPLES OF COMPONENTS AND ASSEMBLIES	DIMENSIONAL PREFERENCE (mm)		
		First	Second	
A: Small Components (under 500 mm)	Brick, block, tile, paving units	100 200 300 400	25 50 75 150 250	
B: Medium-size Components and Assemblies (under 1500 mm)	Sheets, panels, partition units, doorsets, windows, slabs	600 800 900 1200	500 700 1000 1400 *Note 1	
C: Large-size Components and Assemblies (up to 3600 mm)	Precast floor units, precast wall units, panels, door assemblies, window assemblies, precast stairs, precast ducts	1800 2400 3000 3600	(n x 300) 1500 2100 2700 3300 *Note 2	(n x 200) 1500 2000 2200 2600 2800 3200 3400
D: Very Large Components and Assemblies (over 3600 mm)	Prefabricated building elements, precast floor and roof sections,	4800 6000 7200 8400 9600 10 800 12 000	(n x 600) 4200 6600 7800 9000 10 200 11 400 *Note 3	(n x 1500) 4500 7500 10 500

NOTES: 1. *For the purposes of rationalization, those multiples of 100 mm, above 1000, which are prime numbers (e.g., 1100, 1300, 1700, 1900, 2300, 2900, etc.) constitute a lower order of preference and should only be considered where special requirements exist.*

2. *Alternative second preferences are shown; for vertical dimensions the use of multiples of 300 mm, particularly in conjunction with masonry materials.*

3. *Alternative second preferences are shown; for some projects it will be more appropriate to size large components or assemblies in multiples of 1500 mm.*

4.8 Construction - The Trade-off Between Design Dimensions and Product Sizes

Efficient construction involves the positioning and assembly of a variety of building components from different sources into an organized and functional whole with a minimum of cutting, fitting, or other waste of effort and materials. Modular construction has long been looked at as a means of obtaining greater efficiency in construction and, thus, stabilizing building costs.

Efficient construction, to some extent, depends on the harmony of design dimensions and building product sizes, as any mismatch requires cutting and/or fitting of materials. Obviously, some cutting will always be needed around openings, projections, or corners, but the intelligent use of preferences can reduce its amount without resulting in stereotypes. This applies regardless of the measurement system used.

However, for reasons discussed earlier, the visibility and divisibility of metric preferred dimensions would offer opportunities for savings right through the building design and construction processes. A trade-off matrix for preferred design dimensions and product sizes was developed in Australia, and has been refined for U.S. use. The matrix is an original "metric decision aid," but it could be duplicated in customary dimensions, based on the 4-inch module.

The matrix, in table 4-3, shows on the horizontal axis a selection of dimensional preferences for building products between 100 mm and 1200 mm, and on the vertical axis design dimensions from 200 mm to 6000 mm. In the squares of the matrix, where appropriate, divisibility of the design dimensions is indicated by numerals which show the multiple of preferred product dimensions. The summary columns list the total divisibility of modular design dimensions as well as the two non-modular dimensions included. It gives a very clear indication why, for example, 3600 mm is a better design dimension than its neighbors, 3500 mm and 3700 mm, since it represents a whole multiple of many different modular product dimensions. All prime number modules, such as 3700 mm, have been shown in italics to indicate that they offer more limited value in modular coordination. The matrix can be expanded, and readily adapted for computer design decisions.

4.9 Modular Drawing Practice

Modular drawing practice has relied heavily on the use of modular grids to control dimensions, sizes, and position, using either the basic module or multimodules as grid intervals. Grids are also used in metric dimensional coordination to facilitate precoordination decisions in designs, but more emphasis is placed on controlling lines, such as floor or ceiling planes, which are shown with a little circle at the end. An open 45-degree arrow replaces solid arrows in the identification of modular controlling or coordinating dimensions.

4.10 The Development of Standards for Dimensional Coordination in Building

The United States has the distinction of having had the first national standards committee on "the coordination of dimensions in building," namely Project A62 in the American Standards Association in 1939, which prepared a series of four national standards based on a 4-inch module, between 1945 and 1957 [4]. Another burst of modular standards activity took place after the American Standards Association changed its name to USA Standards Association and, a little later, to the present name, American National Standards Institute (ANSI), with four additional standards in the A62 series issued between 1968 and 1971 [5].

In 1974, the responsibility for the development of standards dealing with dimensional coordination was transferred from ANSI to the American Society for Testing and Materials (ASTM), and a new Subcommittee E.6-62

Table 4-3: Matrix of Modular Design Dimensions vs. Modular Product Sizes to Show Whole Multiples of Product Sizes and the Extent of Modular Options in the Range 200 mm to 6000 mm

	Product Dimensions													Modular Multiples	Other Multiples
Building Design Dimensions	100	150	200	250	300	400	500	600	700	800	900	1000	1200		
200	2		1											2	-
300	3	2			1									2	1
400	4		2			1								3	-
500	5			2			1							2	1
600	6	4	3		2			1						4	1
700	7								1					2	-
800	8		4			2				1				4	-
900	9	6			3						1			3	1
1000	10		5	4			2					1		4	1
1100	11													1	-
1200	12	8	6		4	3		2					1	6	1
1300	13													1	-
1400	14		7						2					3	-
1500	15	10		6	5		3							3	2
1600	16		8			4				2				4	-
1700	17													1	-
1800	18	12	9		6			3			2			5	1
1900	19													1	-
2000	20		10	8		5	4					2		5	1
2100	21	14			7				3					3	1
2200	22		11											2	-
2300	23													1	-
2400	24	16	12		8	6		4		3			2	7	1
2500	25			10			5							2	1
2600	26		13											2	-
2700	27	18			9						3			3	1
2800	28		14			7			4					4	-
2900	29													1	-
3000	30	20	15	12	10		6	5				3		6	2
3100	31													1	-
3200	32		16			8				4				4	-
3300	33	22			11									2	1
3400	34		17											2	-
3500	35			14			7		5					3	1
3600	36	24	18		12	9		6			4		3	7	1
3700	37													1	-
3800	38		19											2	-
3900	39	26			13									2	1
4000	40		20	16		10	8			5		4		6	1
4100	41													1	-
4200	42	28	21		14			7	6					5	1
4300	43													1	-
4400	44		22			11								3	-
4500	45	30		18	15		9				5			4	2
4600	46		23											2	-
4700	47													1	-
4800	48	32	24		16	12		8		6			4	7	1
4900	49								7					2	-
5000	50		25	20			10					5		4	1
5100	51	34			17									2	1
5200	52		26			13								3	-
5300	53													1	-
5400	54	36	27		18			9			6			5	1
5500	55			22			11							2	1
5600	56		28			14			8	7				5	-
5700	57	38			19									2	1
5800	58		29											2	-
5900	59													1	-
6000	60	40	30	24	20	15	12	10				6	5	8	

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was formed to deal with "Coordination of Dimensions for Building Materials and Systems," under the jurisdiction of Committee E.6, Performance of Building Constructions.

To date, ASTM Committee E.6 has issued only one standard, ANSI/ASTM E577-76, Standard for Dimensional Coordination of Rectilinear Building Parts and Systems [6]. It uses a novel approach of designating dimensional preferences by the symbol "U" (for unit dimension), and assigning values to U in both metric (SI) and U.S. customary units. The U represents both 100 mm in metric units and 4 inches in U.S. customary units, as the standard increment and the standard spacing in a modular grid. The standard implies that at some future date dimensional coordination based on a 100 mm module is likely to take over from dimensional coordination based on the 4-inch module, and that the general principles may be applied regardless of unit choice. But the duality could lead to problems in production and construction, since modular metric products will not be interchangeable with modular customary products, and vice versa. The standard is under review, and it has been suggested that it should be replaced by a companion standard in two separate issues, one entirely in metric units, and the other entirely in U.S. customary units.

ASTM Committee E.6 has under consideration a proposed standard on "Dimensional Coordination of Structural Clay Units, Concrete Masonry Units, and Clay Flue Linings," as companion standards with separate metric and customary versions. The ideas advanced in the draft standard are not new; much of the content is based on material contained in former ASA (ANSI) standards A62.2-1945, A62.3-1946, and A62.4-1947. The comparison standards are discussed in more detail in 5.3.

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PART 5 - PROPERTIES AND SIZES OF METRIC BUILDING PRODUCTS—PRECEDENT, CHANGES PROPOSED, AND CHANGES MADE

5.1 Metrication and Building Products - Some General Observations

A change to metric (SI) units in construction would require the review of the dimensions and physical properties of most building materials, components, and assemblies. Before selecting new sizes, it would be desirable to assess the impact of metrication, difficulties associated with the change-over, opportunities for rationalization and variety reduction, and alternative strategies for conversion.

Initially, many products would require no change other than their description in metric terms and/or adjustment within existing production tolerances. This metric veneer is termed a "soft conversion" to equivalent metric values within tolerances, since the only changes that would be made would occur on paper—in the software. Where dual labeling is used, it would not even be necessary to keep separate inventories. In a soft conversion, a manufacturer would seek out "convenient" numerical values, rather than preferred metric values; for example a 12 inch length (304.8 mm) would simply be shown as 305 mm. Generally, a soft conversion allows producers to postpone changes to new and preferred sizes or properties until the next redesign or new product development.

On the other hand, to take advantage of "preferred metric dimensions or sizes," other products would require a "hard conversion," that is, a change to new and non-interchangeable sizes, to fit in with industry preferences or to reduce variety. The term "hard conversion" is used not only because such a change is often more difficult, but because the hardware is changed so that separate inventories would have to be kept. A typical hard conversion would involve a change from multiples of 4 inches (101.6 mm) to multiples of 100 mm; for example, a 12 inch (304.8 mm) component would be replaced by a 100 mm component.

Metric changes could be attempted one-at-a-time, or simultaneously, with all changes to a product occurring at the same time. In the first case, the costs may be spread over a greater period of time; however, it could require successive revision of technical data, which may reduce its cost-effectiveness.

The principal theme associated with change should be "rationalization through metrication." This means that product ranges should be reviewed for functional and economic efficiency, for example, whether the range carried presents an optimum range, or whether the steps within a range are really the best or only exist because of tradition and historical factors. A change to metric products could lend itself to the pruning of products that have been liabilities, either as a result of long shelf-life and slow sales, or poor contribution to profit. In some instances, product lines could be reduced without costs to the producer, designer, or user, but with gains to the producer, distributor, or contractor. Some examples are discussed in the assessment of specific product groups.

Metric production considerations are discussed in Section 4, of NBS Special Publication 530 [1], dealing with "Managerial and Economic Considerations in the Change to a Metric Production Environment." Guidance on conversion strategies and the selection of convenient and preferred metric values is given in NBS Technical Note 990, "The Selection of Preferred Metric Values for Design and Construction" [2].

5.2 International Precedent as a Guide

Although the U.S. construction community has a larger turnover than that of any other country, the precedent of metric production decisions from other countries offers many useful suggestions of how to adapt to metric with a minimum of cost and disruption, and of the pitfalls that should be avoided.

Precedent from Britain, South Africa, New Zealand and Australia is already dated by time, and many of the people who made the decisions or managed the resulting changes have already retired. In any case, Canadian precedent is the most relevant guide, because of the many similarities in construction technology and practices, joint participation in standards development activities, interlocking industrial ownerships in many segments of industry, as well as a general exchange of technological ideas and research findings. In addition, Canada is geographically closest and is now in the transitional stages of metric conversion in the construction industries—the Canadian M-Day for construction was on January 1, 1978—so that it presents an ideal learning model for the United States. While it has been suggested that, due to the much larger U.S. economy, metric adaptation costs and problems would be greater than elsewhere, (in the case of the concrete block industry the relative size of Canada and the United States has been used as a factor in cost estimates). These predictions of cost have tended to ignore three aspects that would facilitate a change in the United States:

1. A larger economy allows a "progressive change" with manufacturers changing when it is economically most advantageous, and <u>not</u> all at the same time. As metric demand builds up, more and more organizations would change.

2. Lead-times now available allow for optimum planning of equipment obsolescence and replacement decisions.

3. With variety reduction, larger and longer production runs are possible, which would reduce unit costs.

In the discussion of metric progress and proposals in various industry segments, Canadian precedent will serve as an illustration of "metric trailblazing," particularly as Canadian industry is now producing products based on joint United States/Canada proposals.

5.3 Metrication and Masonry Products

Masonry units, made from fired clay or concrete, have traditionally been of modular sizes. The masonry products industry has not taken a definitive stand on metric dimensions and sizes, but some masonry industry leaders see the value of metric masonry products as a backbone in metric dimensional coordination. As in other countries that have converted, metric masonry unit sizes would probably be determined early on and be available when needed. Early predictions of greater costs associated with the change have not materialized in other countries, because the available lead-time was used to minimize costs by taking advantage of planning obsolescence in production machinery, and normal replacement cycles for extrusion dies and molds. Also, some products now produced are within tolerances of metric sizes, such as the 7-1/2" brick.

As noted in 4.10, the American Society for Testing and Materials (ASTM) Committee E.6 is in the process of developing a standard for "Dimensional Coordination of Structural Clay Units, Concrete Masonry Units, and Clay Flue Linings," to be issued in two non-interchangeable companion documents, one in SI units and the other in U.S. customary units. The metric version will have preferred dimensions based on the 100 mm module. A significant difference is that the metric standard proposes only two standard joint thicknesses, 10 mm and 5 mm, compared with three standard joint thicknesses in customary units (1/2", 3/8", and 1/4"), for brick and facing tile, thus reducing variety in design detailing and production.

5.4 Metriciatior and Building Lumber

The lumber and wood products industry has studied metric issues for the past five years as part of the work of the ANMC Lumber and Wood Products Sector Committee and its ten Subsectors. The industry has relaxed its early activities based on the assumption that most issues have been resolved and that there is no great pressure for conversion within the industry or on the industry. A general statement of the industry's metric position in mid-1978 is contained in "Lumber and Wood Products Metric Planning Package" [3], issued by the National Forest Products Association.

On page 4, the document proposes a soft conversion of existing widths and thicknesses of softwood building lumber, with marginal rounding down in the larger sizes. (Tables 1-5, pages 12-16.) Widths and thicknesses will be designated in millimeters (mm) and in net dimensions rather than current nominal sizes. Lengths will be hard converted in multiples of 600 mm, coordinated with proposed building dimensions based on the 100 mm module and proposed metric sizes of panel products.

In marketing and costing, lengths will be shown in meters (m). The proposed sizes would probably be reevaluated during and after an actual conversion, when both producers and users realize that greater rationalization is possible with preferred sizes that suit the needs of the industry, and facilitate the design and construction processes.

5.5 Metrication and Concrete

The concrete industry would likely be a lead sector in any metrication effort as it has been in other countries that have made the change. Modifications necessitated by the change to SI are not extensive, but the potential for variety reduction and rationalization is considerable.

5.5.1 Bulk Materials for Use in Concrete. Constituent materials used in the manufacture of concrete would not represent major problems in a change to metric (SI) units. Sand and aggregates could be delivered by the metric ton (t) instead of the U.S. short ton. Where volume is preferred, such as in paving, the cubic meter (m^3) could replace the cubic yard (yd^3) and cubic foot (ft^3). Water could be measured in terms of liters [L] instead of U.S. gallons. As mentioned earlier, the relationship of the liter cube and kilogram, and their derivation from the cubic meter (1 L = 0.001 m^3; 1 L of water at S.G. of 1.0 = 1 kg) would facilitate mix and placement calculations. Cement is a powder and would not require any modifications in the manufacturing process. However, bulk cement could be sold by the metric ton (t), while bagged cement would probably be shipped in 40 kg bags (25 bags per metric ton), replacing the current 94 lb. bag (42.6 kg).

5.5.2 Ready-Mixed Concrete. Ready mixed concrete could be delivered by the cubic meter (m^3), approximately 1.3 cubic yards, but increment steps for orders could be a matter for local determination within broad overall guidelines. Concrete strength grades could be expressed in megapascals (MPa) instead of psi, in a regular progression with fewer steps than at present. It is likely that 5 MPa steps would be used, such as: 15 MPa (2175 psi); 20 MPa (2900 psi); 25 MPa (3625 psi); 30 MPa (4350 psi); 35 MPa (5075 psi); and 40 MPa (5800 psi). For higher strengths, increments of 10 MPa would likely be preferred.

5.5.3 Concrete Reinforcing Steel. A change to metric (SI) units would present an opportunity for the review and rationalization of reinforcing steel sizes and ranges. This fact is well recognized by the Concrete Reinforcing Steel Institute (CRSI), which has been involved in detailed studies and discussions with Canada to bring about a new and rationalized range of reinforcement in North America.

Proposals are based on preferred sizes derived from the principal design criterion, cross-sectional area, and the use of sizes in select multiplies of 100 mm^2. The metric sizes, which are the subject of a standby standard prepared within ASTM, are already in use in Canada. They involve a reduction in range from the 11 current sizes to 8 metric sizes, and, therefore simplification of production, distribution, fabrication, and design activities. Five of the eight new sizes are within weight tolerances of existing bars, which means that roll changes are needed for only three bar sizes.

Two Canadian standards provide details of the geometrical and other properties of the new range: CSA Standard G30.12-M1977, Billet-Steel Bars for Concrete Reinforcement [4]; and, CSA Standard G30.16-M1977, Weldable Low Alloy Steel Deformed Bars for Concrete Reinforcement [5]. Table 1 in both standards is identical and has been reproduced for information:

Table 1
Deformed Bar Designation Numbers*, Nominal Dimensions†, Unit Masses, and Deformation Requirements

Bar Designation Number	Nominal Dimensions: Cross-Sectional Area mm^2	Nominal Dimensions: Diameter mm	Nominal Dimensions: Perimeter mm	Mass (Weight) Per Unit Length kg/m	Deformation Requirements mm: Maximum Average Spacing	Deformation Requirements mm: Minimum Average Height	Deformation Requirements mm: Maximum Gap Chord of 12.5 Per Cent of Nominal Perimeter
10	100	11.3	35.5	0.785	7.9	0.45	4.4
15	200	16.0	50.1	1.570	11.2	0.72	6.3
20	300	19.5	61.3	2.355	13.6	0.98	7.7
25	500	25.2	79.2	3.925	17.6	1.26	9.9
30	700	29.9	93.9	5.495	20.9	1.48	11.7
35	1000	35.7	112.2	7.850	25.0	1.79	14.0
45	1500	43.7	137.3	11.775	30.6	2.20	17.2
55	2500	56.4	177.2	19.625	39.4	2.55	22.2

* *Bar numbers are based on the number of millimetres included in the nominal diameter of the bars.*

† *The nominal dimensions of a deformed bar are equivalent to those of a plain round bar having the same mass per metre as the deformed bar.*

The cross-sectional areas for conventional bars [#3 to #18] are given for comparison purposes and metric replacements are shown below:

Customary Designation	#3	#4	#5	#6	#7	#8	#9	#10	#11	#14	#18
Area in mm^2	71	129	200	284	387	510	645	819	1006	1452	2581
Metric Area/ Designation	100		200	300		500	700		1000	1500	2500

The 100 mm^2 rebar replaces both #3 and #4; the 700 mm^2 rebar replaces both #9 and #10. Only #7 (7/8" ϕ) has no metric equivalent, and its use should be limited as the transition period approaches to avoid the possibility of non-availability after a change is implemented. Some buildings may be built during the change from one range to another, and foreknowledge of metric proposals will minimize adaptation problems.

5.5.4 Precast and Manufactured Concrete Products. While in-situ concrete construction in metric units would be a matter of fairly simple dimensional adaptation by setting formwork to metric spans, spacings, or other design dimensions, manufactured concrete products made in forms or on casting beds to foot-inch dimensions could present more adjustment problems.

For example, prestressed structural sections, such as T-beams or double T-beams, could be produced to metric preferred lengths without much difficulty; however, nominal width preferences would require a definite change from foot-inch width to metric widths. In the case of a typical section with a coordinating width of 8'-0", a change to a metric width of 2400 mm would require a reduction of 1-1/2" (or 38 mm) overall, or 3/4" (19 mm) on each side. This might be accomplished by the insertion of a 3/4" filler piece on each side, if the sides of the form are not adjustable. Otherwise, the profile would probably remain unaltered until the form is replaced, renewed, or possibly superseded by a new design in metric preferred dimensions.

Lead-times available now could be well used by identifying lifecycles of casting forms, potential new designs, and alternative adaptation strategies to enable a cost-effective adjustment to a metric building environment.

5.5.5 Concrete Design Data and Technical Information. The American Concrete Institute (ACI) and the Prestressed Concrete Institute (PCI) have endorsed metrication, based on an orderly and planned approach. In view of their international constituencies, both institutes are actively engaged in developing a metric technical data bank for concrete and concrete products. ACI has an active Board Committee on Metrication, and has an Institute policy to develop a hard metric version of the key technical document prepared by Committee 318, "Building Code Requirements for Reinforced Concrete" [6], by 1983, with the parallel publication of related standards by that time.

5.6 Metrication and Metal Products

5.6.1 Structural Steel Sections. The principal ANSI/ASTM standard for structural steel products, A6-78, "Standard Specification for General Requirements for Rolled Steel Plates, Shapes, Sheet Piling, and Bars for Structural Use" [7], contains metric equivalents and metric dimensions and properties for standard shape profiles in the Annex. A more extensive listing of properties is contained in the Canadian standard CAN3-G312.3-M78, "Preferred Metric Dimensions for Structural Steel W and HP Shapes, Angles, and Hollow Structural Steel Sections" [8].

Whereas the Canadian Standard uses the same sizes and designations for W and HP Shapes, equal leg angles and unequal leg angles have been rationalized in metric dimensions and thicknesses, as tabulated below.

CAN3 - G312.3-M78, Table 3

Equal Leg Angles [Metric]

Size (mm)	3	4	5	6	8	10	13	16	20	25	30
25x25	x	x	x								
35x35	x	x	x	x							
45x45	x	x	x	x	x						
55x55	x	x	x	x	x	x					
65x65			x	x	x	x					
75x75			x	x	x	x	x				
90x90				x	x	x	x				
100x100				x	x	x	x	x			
125x125					x	x	x	x			
150x150						x	x	x	x		
200x200						x	x	x	x	x	x

Total Range: 50

CAN3 - G312.3-M78, Table 4

Unequal Leg Angles [Metric]

Size (mm)	3	4	5	6	8	10	13	16	20	25
45x30	x	x	x	x						
55x30	x	x	x	x						
65x50		x	x	x	x					
75x50			x	x	x					
80x60			x	x	x	x				
90x65			x	x	x	x				
90x75			x	x	x	x	x			
100x75				x	x	x	x			
100x90				x	x	x	x			
125x75				x	x	x	x			
125x90					x	x	x	x		
150x100					x	x	x	x		
200x100						x	x	x	x	
200x150							x	x	x	x

Total Range: 56

The steel industry has identified metrication as an opportune time to make some changes and to rationalize product lines for more efficient operations. For example, the 43 sizes for steel plates in customary units have been replaced with 28 metric sizes; a reduction in variety by 35 percent, which will facilitate production, distribution, fabrication, and design detailing once a transition has been made.

A range of American National Standards [9] and identical Canadian standards [10] exists which provide guidance on preferred sizes for metric steel products other than structural shapes and other [illegible] products:

ANSI B32.3-1977 — Preferred Metric Sizes for Flat Metal Products (Corresponding Canadian Standard is CAN3-G312.1-75)

ANSI B32.4-1977 — Preferred Metric Sizes for Round, Square and Hexagon Metal Products (Corresponding Canadian Standard is CAN3-G312.2-76)

ANSI B32.5-1977 — Preferred Metric Sizes for Tubular Metal Products Other Than Pipe

~~ANSI B32.6-1977~~ — ~~Preferred Metric~~ Equivalents of Inch Sizes for Tubular Metal Products Other Than Pipe

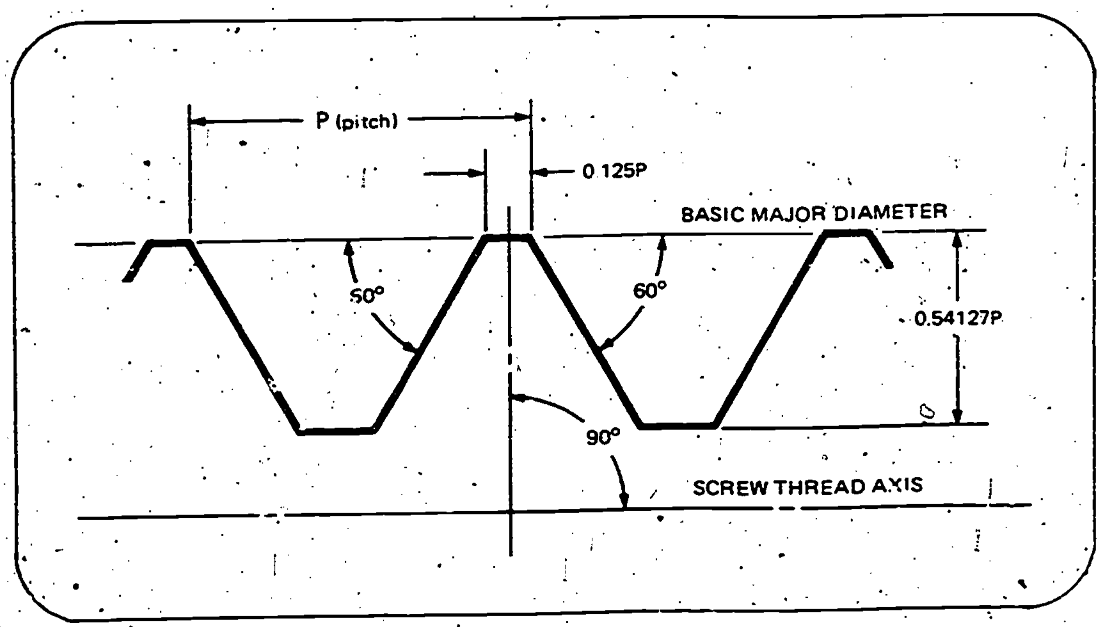
Most steel standards issued by ASTM now have dual dimensions, and a few have a separate, hard converted metric version designated by the suffix "M" after the standard identification number; for example:

ASTM A568M-77 Standard Specification for Steel, Carbon and High Strength Low Alloy Hot Rolled Sheet and Cold Rolled Sheet — General Requirements (Metric) [11]

5.6.2 Fasteners. The fasteners industry is on the way to a single system of international fastener standards. The Industrial Fasteners Institute (IFI), in Cleveland, Ohio, has conducted extensive studies into an optimum system of metric mechanical fasteners and fastener application engineering, and has found that significant economic and technical benefits can be shared by users and producers of fasteners if advantage is taken of technical improvement opportunities, more efficient use of materials, and "reduction" in the number of different parts.

After five years of research and technical investigation, as well as liaison with ISO technical committees, the Industrial Fasteners Institute published a series of "Metric Fasteners Standards" [12] in 1976, which provided for significant product rationalization. Screw threads were based on the ISO basic thread profile shown in Figure 5-1, and the standards allowed for only one series of diameter-pitch combinations, rather than "coarse" and "fine" threads.

Figure 5-1: ISO Basic Thread Profile



Of particular interest to engineering and construction may be standards for bolts, screws, nuts, rivets, and other fasteners. IFI Standard 526 [12] deals with "Metric High Strength Structural Bolts, Nuts and Washers," and covers nominal lengths from 45 mm to 300 mm, in the following increments:

45 mm to 100 mm: Incremental lengths of 5 mm
100 mm to 300 mm: Incremental lengths of 10 mm

Nominal bolt sizes are designated by a capital M, followed by the nominal body diameter (e.g., M20 for 20 mm) and an indication of thread pitch in millimeters (e.g., 2.5 for 2.5 mm). The following combinations are listed:

45 and 55 mm: M16x2
55 and 60 mm: M16x2, M20x2.5
65 and 70 mm: M16x2, M20x2.5, M24x3
70 and 75 mm: M16x2, M20x2.5, M24x3, M30x3.5
70 to 300 mm: M16x2, M20x2.5, M24x3, M30x3.5, M36x4

This abbreviated listing is indicative of the simplicity of the metric range.

The IFI Metric Fastener Standards are in the process of being revised, and a new edition is anticipated in the first quarter of 1981. Some modifications have been made to bring the entire metric fastener system into line with ISO standards.

Metric fasteners are being used widely in industrial applications, particularly in the automotive industry.

5.6.3 Steel Tubes and Pipes. It is likely that most steel tube and pipe products will initially be "soft converted" to equivalent metric sizes.

However, the Tube and Steel Company of America [Tascoa], of New York, indicated in a May 1980 new release [13], that the company is leading the way to metric sizes and that hard metric sizes are available for the following tubing:

Squares	Rectangles
30 mm x 30 mm	25 mm x 50 mm
40 mm x 40 mm	40 mm x 80 mm
50 mm x 50 mm	50 mm x 100 mm
60 mm x 60 mm	60 mm x 120 mm
100 mm x 100 mm	80 mm x 140 mm
120 mm x 120 mm	100 mm x 180 mm
125 mm x 125 mm	150 mm x 200 mm

The release further stated that additional sizes of 150 mm x 150 mm and 175 mm x 175 mm would be added to the range, and that with the planned addition of a new mill in April 1981, production capability of "hard" metric sizes would be increased.

5.6.4 Other Metals - Aluminum, Brass, Copper, Lead, and Zinc. Planning for metrication is well advanced in the aluminum industry. Through committees of the Aluminum Association, the industry has been preparing for metric conversion for nine years. In 1978, it issued a "hard metric" version of its basic reference document, "Aluminum Standards and Data" [14], using logical metric values for long-term use rather than restating customary values in metric terms by the use of conversion factors.

The Aluminum Company of America (ALCOA) recently published preferred metric sizes for its aluminum sheet and plate products, in line with ANSI standards; and details are available through the Aluminum Association, the National Association of Aluminum Distributors, or the American National Metric Council.

At the national level, the Metals Sector Committee of the ANMC Materials Coordinating Committee has developed an outline plan and schedules for the change to SI in the metals industries. Timing of metric production, generally, is complementary to the recommended construction industries metric conversion schedule.

5.7 Glass Products

A change to metric (SI) units would permit some dimensional rationalization of glass thicknesses, with metric designations given in millimeters (mm) and whole numbers rather than fractions. A system of permissible tolerances on thickness would mean that some of the existing glass thicknesses would be fully interchangeable with new metric thicknesses. Additionally, tolerances for length and width of cut sizes have been related to glass thickness, so that a metric accuracy system could likely lead to better fit and functional performance of glazed elements.

The standards adopted by the Canadian glass industry [15] provide a good guide to the direction in which the metric change could head, especially as one of the principal glass suppliers in Canada, PPG Industries Canada Ltd., is affiliated with PPG Industries in the United States. The principal metric standards include:

CAN2-12.1-M79	Glass, Safety; Tempered
CAN2-12.2-M76	Glass, Sheet or Laminated; Flat, Clear
CAN2-12.3-M76	Glass, Polished Plate or Float; Flat, Clear
CAN2-12.4-M76	Glass, Heat Absorbing
CAN2-12.8-M76	Glass, Insulating Glass Units
CAN2-12.9-M76	Glass, Spandrel
CAN2-12.10-M76	Glass, Light and Heat Reflecting for Building Construction

CAN2-12.11-M76 Glass, Wired; Safety
CAN2-12.12-M79 Glass Sheets, Plastic, Safety
CAN2-12.13-M79 Glass, Patterned

The principal dimensional standards for sheet or laminated, polished plate or float, insulating glass units, and spandrel glass are shown in table 5-1.

Table 5-1. Principal Dimensional Standards-Glass Products

Nominal Thickness (mm)	Thickness Tolerance (mm)	Cut Size Length and Width Tolerance (mm)	Canadian National Standard CAN2-Series 12.2M	12.3M	12.8M	12.9M
2	± 0.3	± 2.0	x		x	
3	± 0.5	± 2.0	x	x	x	x
4	± 0.5	± 2.0	x	x	x	x
5	± 0.5	± 2.0	x	x	x	x
6	± 0.5	± 2.0	x	x	x	x
8	± 0.8	± 2.5	x	x		x
10	± 1.0	± 2.5	x	x		x
12	± 1.0	± 3.0	x	x		x
15	± 1.0	± 4.0	x	x		
19	± 1.0	± 5.0	x	x		
22	± 1.0	± 6.0		x		
25	± 1.0	± 6.5		x		

Wired safety glass comes in 6 mm thickness (+1.5; -0) and 10 mm thickness (+0.5; -1.5).

5.8 Panels, Sheets, and Tile

Rigid or flexible sheet and tile materials for use on vertical and horizontal surfaces in buildings are dimensionally significant, inasmuch as they generally bear a relationship to preferred dimensions. Customary products have nominal sizes related to multiples of feet, or inches, and there is a general fit with the 4-inch building module, except for floor and wall tile.

As part of a change to metric dimensions, these products probably would change to whole multiples of millimeters, and, as new products are introduced or product lines rationalized, to metric preferred sizes coinciding with whole multiples of the 100 mm building module. Some producing sectors have indicated their recommended preferred sizes. For example, the metric advisory committee of the American Plywood Association recommends a metric panel size of 1200 x 2400 mm for sheathing grades of plywood, thus permitting a direct relationship between preferred spacing of structural members and the sizes of plywood.

Concerns have been expressed by segments of the gypsum board industry that a "hard conversion" to a metric board size of 1200 x 2400 mm would cause losses in productivity and output, and that a soft conversion of existing sizes to a metric size of 1200 x 2440 mm (or 1219 x 2438 mm) would be preferable.

A soft conversion of existing sizes, without any change or changes within production tolerances, could be an interim solution which may be supplanted by genuine "hard" metric sizes should building designers begin to specify such products and contractors demand them for use in metric building projects. The concern is not new—it was expressed in Britian, Australia, and Canada—but in each case the industry rapidly moved to preferred metric sizes as demand for products developed. The lead-time available now might be used to assess any equipment obsolescence, so that replacement machinery could be introduced to coincide with a change to metric sizes. In Canada, 1200 x 2400 mm, 1200 x 3000 mm, and 1200 x 3600 mm gypsum wallboard or ceiling panels, and 600 x 2400 mm and 1200 x 2400 mm gypsum sheathing board are now being supplied by Canadian Gypsum and Westroc Industries.

5.9 Roofing

Roofing materials include metal decking, shingles, tile, bituminous felts and a variety of specialized materials and systems made from asbestos-cement, fiberglass reinforced polyesters, etc. Dimensional considerations involve effective cover and overlaps, size and shapes of profiles, and effective span between supports.

Due to the variety of origins and the relative simplicity of site modification by cutting or adjustment (of overlap or projection), there has been no strong dimensional discipline in traditional roofing materials and systems. A change to modular metric dimensions would permit a reappraisal of approaches and provide an opportunity for rationalization of sizes, spacings, and overlap.

The first industrial segment of the roofing industry to have assessed the opportunities of metrication in the wake of the Canadian experience is the asphalt roofing shingle segment. "Metric shingles," approximately 18 percent larger than customary shingles, are in production in California (Thagard Oil Company) and in New England (Reynolds Aluminum Building Products Company), and have gained wide acceptance. The shingles are 1000 mm (39-3/8") (1 meter) long, and 336 mm (13.25") wide, and are produced on the same manufacturing plant, requiring very little new equipment. Reports on the production, use, and acceptance of these shingles are contained in ANMC Metric Reporter issues of March 21, 1980, and July 1, 1980 [16].

Proposals have also been made in the metal roofing segment to introduce a metric profile for roll-formed metal decking, with an effective cover width of 1000 mm (39-3/8") to take the place of the traditional width of 36 inches (915 mm), an effective increase in width of approximately nine percent. The length of metal roof decking represents no major problem in the longer term, as stock length could be adjusted to suit metric preferences, and special lengths would be available on large order quantities in the same manner as now.

5.10 Construction Assemblies - Doors, Windows, Partitions, Skylights, etc.

Composite building assemblies, such as doors (including frames), windows, partitions, and skylights, could be designed and manufactured to suit dimensionally coordinated openings in walls or roofs. It is important to realize that in a metric building environment the size of the opening rather than the size of the product or assembly is regarded as the critical determinant. The reason, basically, is simple: if products are manufactured to fit into a standard range of preferred openings, variety reduction can take place in manufacturing while simultaneously providing the designer with alternative, though standard, choices. This approach could lead to better products and containment of construction costs. Special requirements in prestige buildings or unusual structures could be catered for as is done now—by individual or batch production of special assemblies.

A change to metric preferred dimensions could be a unique point in time at which to reappraise standard details, or to develop standard details where none exist. If precedent is any guide, the use of a single unit of measurement—the millimeter (mm)—for the layout of openings, the manufacture of components, and the specification of tolerances leads to better accuracy in building.

5.11 Stairways and Built-in Elements

The standardization of floor-to-floor heights (story heights) in buildings makes it attractive to standardize stair design and detailing, in concrete as well as steel or wood. This could enable a higher degree of prefabrication, especially as the early availability of stairs on medium or high rise building projects facilitates construction activities and improves on-site safety. The use of millimeters for the geometric layout and detailing of stairs (overall dimensions as well as rise and run) would facilitate design, manufacture, and construction, and make it possible to avoid or reduce inaccuracies, especially uneven riser height, and thus improve stair safety.

Preferred horizontal and vertical dimensions in building facilitates the integration of large, precast or prefabricated components and elements. Again, the elemental dimensions would be expressed in the same measurement units as the tolerances and clearances for positioning and fit, thus reducing the likelihood of mismatch. Overall, metric design and construction could likely lead to neater solutions.

5.12 Services Systems: Electrical, Lighting, Air-Conditioning, Plumbing, etc.

A transition to "metric" dimensions and configurations in building services would likely be a slow and gradual one, characterized by rationalization of sizes and ranges wherever practicable. If the industry determines an M-Day, new product development is almost certain to be carried out in metric units, and to metric preferences. Electrical wiring sizes may change following a research evaluation of present sizes and the potential for optimization to benefit designers, producers, and users. Plumbing pipes unlikely would require more than a soft conversion of "nominal" designations, except for the chance to classify all alternatives according to the same principles, possibly internal diameter or cross-sectional area. Air-conditioning ducts may change with new sheet metal sizes, and some preferred metric duct configurations have been indicated in American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) documents.

Fixtures, fittings, and accessories could be changed to metric preferred sizes where this is essential to their "coordination," but need not otherwise be changed, except when new products are developed. Among the fixtures and fittings which may require a hard conversion are components that are integrated into wall or ceiling systems, such as fluorescent lamps for use in modular buildings, and air-conditioning grilles or diffusers.

Considerable investigation has been carried out in the United States and other countries to arrive at a "metric fluorescent lamp," for use in metric modular construction, which would be able to use existing ballast and support systems. A lamp of 1160 mm length has found wide support in discussions within the International Electrotechnical Commission (IEC). The IEC is the international standardization body in the field of electricity and electrical applications. (It is noted that the current 4-foot fluorescent lamp is actually too long for end-to-end mounting of lighting fixtures in modular construction based on a 4-foot ceiling grid, so that designers have had to either modify their layout or select a larger ceiling module, such as 4'-1", 4'-1-1/2", or 4'-2".)

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9. Preferred Metric Sizes for Flat Metal Products, ANSI B32.3-1977; April 1977; 9 pages; and Supplement ANSI B32.3a-1978, August 1978; 1 page.

Preferred Metric Sizes for Round, Square, Rectangle, and Hexagon Metal products; B32.4M-1980; April 1980; 11 pages.

Preferred Metric Sizes for Tubular Metal Products Other than Pipe, ANSI B32.5-1977; September 1977; 8 pages.

Preferred Metric Equivalents of Inch Sizes for Tubular Metal Products Other than Pipe, ANSI B32.6-1977; August 1977; 8 pages.

The above four standards available from the American National Standards Institute, New York, NY.

10. Preferred Metric Dimensions for Flat Metal Products, CAN G312.1-1975; November 1975; 10 pages.

Preferred Metric Dimensions for Round, Square, Rectangular and Hexagonal Metal Products, CAN3-G312.2M-1976; Mary 1976; 11 pages.

The above two standards are available from the Canadian Standards Association, Rexdale, Ontario, Canada.

PART 6 - BUILDING SERVICES AND METRIC CONVERSION

6.1 Overview

Modern buildings are designed to provide a physical and functional environment in terms of indoor climate, electrical services, lighting, hydraulic services, and mechanical equipment, which, in combination account for a substantial part of the total building cost. Rapid escalation in energy costs—which cannot be attributed to metrication—has forced a wholesale reappraisal of design approaches to use energy wisely and to extract the maximum utility out of every energy dollar spent.

It is suggested that metric design for energy conservation and utilization will be simpler than in U.S. customary units because only a few, coherent SI units need to be used, thus making alternatives more directly comparable. Since all units for electrical applications are already SI units, metrication would simply complete the change for other forms of energy.

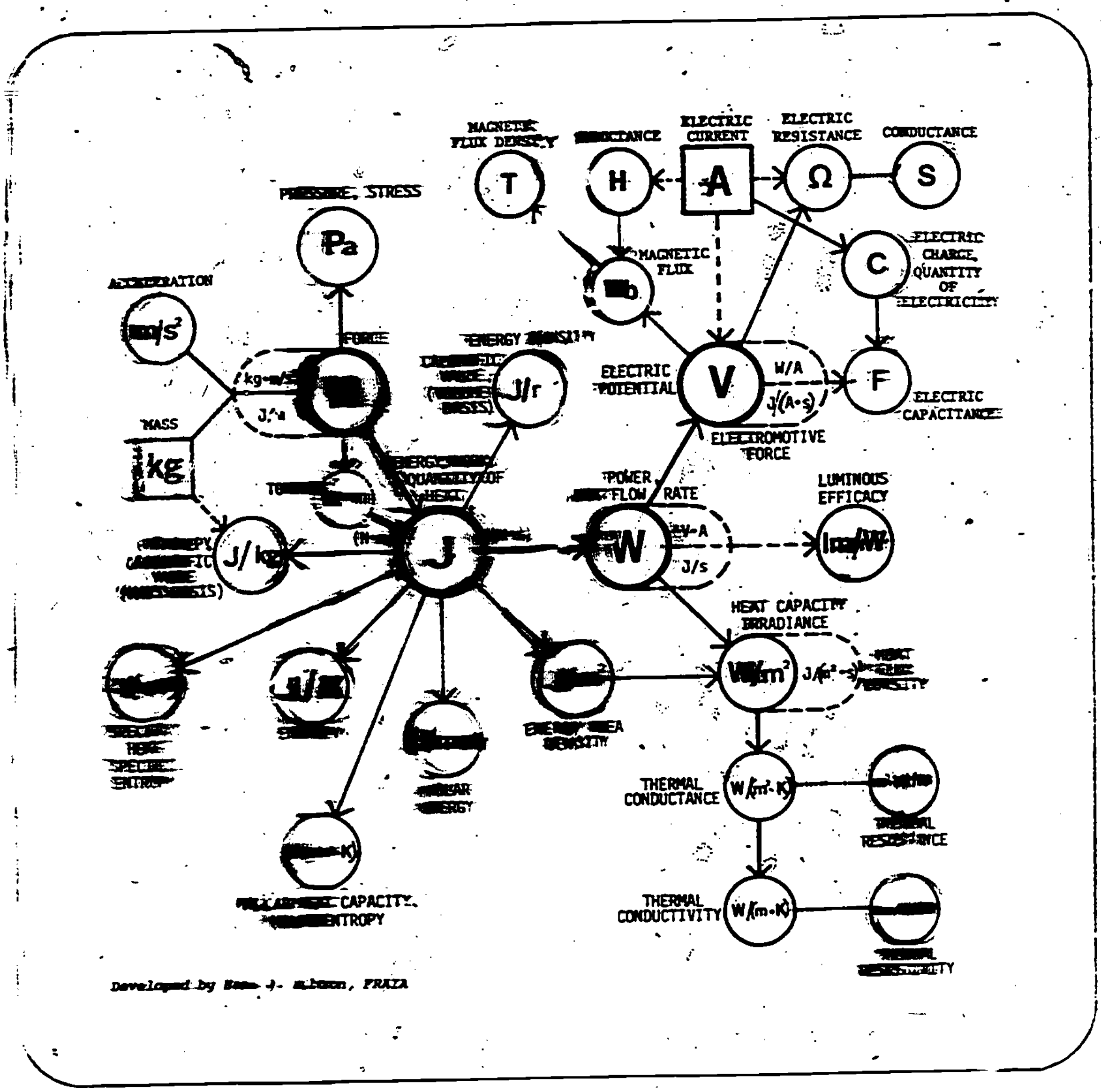
6.2 Coherent Design for Energy Utilization and Conservation

The use of metric (SI) units would make the understanding of thermodynamics and mechanical engineering easier. In line with laws of physics, only one unit, the joule (J), represents all forms of energy, whether mechanical (work), thermal (quantity of heat), electrical, chemical, nuclear, and even molecular, thereby replacing a wide variety of unrelated customary units.

The pivotal role played by the joule is shown in figure 6-1. For example, a force of one newton (N) applied for a distance of one meter (m) will produce one joule of energy or heat. In the same manner, one watt (W) of electric power applied for one second (s) will produce one joule of heat or energy, (1 J = 1 N·m = 1 W·s). More interestingly, the joule remains the numerator in all compound units, which, in a coherent system with one-to-one relationships, will greatly simplify calculations and reduce errors.

It is easy to appreciate the direct relationship between coherent units, when it is compared with the traditional situation, where such units as: Btu, therm, horsepower-hour, foot pound-force, and kilowatt-hour are all used for energy. One SI unit, the watt (W), which is related on a one-to-one basis to the joule, would replace such variety for power or heat-flow as: Btu/s, Btu/h, Btu/d, ft·lbf/s, ft·lbf/min, ft·lbf/h, horsepower, and ton of refrigeration, quite apart from the fact that there are different values for the Btu and the horsepower, depending upon definitions, context, or reference values.

Figure 6-1: The "joule" (J) as Pivotal Unit for Energy Design



Note: Solid arrow lines indicate that the originating unit is a multiplier.
Broken arrow lines indicate that the originating unit is in the denominator.
Dotted lines indicate that the derived unit is the reciprocal of the originating unit.

If the basic concepts of energy are not clearly defined and understood, it becomes very difficult to engage in rational design for energy utilization and conservation. Use of SI units would clarify many hitherto obscure relationships by means of absolute units and system coherence.

6.3 Electrical and Illumination Engineering

Electrical units used in the United States have been metric units since they were first defined between 1860 and 1900. The practical units for resistance (*ohm*), potential (*volt*), current (*ampere*), charge (*coulomb*), and capacity (*farad*) were introduced at the International Electrical Congress in Paris in 1881, and the unit for inductance (*henry*) was added at the Congress in Chicago in 1893. It can be said that "coherence" as part of a unit system was first appreciated in electrical and electromagnetic units. The basis for the use of ampere as the fourth fundamental property—or as a base unit—was provided in 1901, when the Italian professor and physicist Giovanni Giorgi proposed a system which included "The Rational Units of Electromagnetism." [Title of his paper in 1901.] In 1935, the Giorgi (or MKSA) system was adopted by the International Electrotechnical Association, and it played a prominent part in the creation, in 1960, of SI, the International System of Units.

The major breakthrough in SI is the unification of mechanical and electrical units through the watt (W = J/s = V·A) and the joule (J = N·m = W·s), which facilitates most calculations, as indicated in figure 6-1. Electrical units have been included in the figure to illustrate the coherence of SI; for example, the ohm (Ω) could be defined as 1 V/A, or 1 W/A^2, or I/S, but the first definition is the one most commonly shown.

Electrical engineering in the United States, therefore, represents a discipline which uses a hybrid system of SI units for all electromagnetic properties, and U.S. customary units for length and mass, as their derivatives. A change to SI would introduce a minor change in the units already in use, by replacing the "mho" (reciprocal ohm) with the "siemens" (S), and the cycle per second (cps) with the "hertz" (Hz = 1/s)—both on a one-to-one basis, so that numerical values would not be affected. A change to SI would introduce a major change by giving electrical and electronics engineers a fully coherent system to work with when customary units are abandoned. This could increase productivity, especially in design and production. The Institute of Electrical and Electronics Engineers (IEEE) has had an active interest in metrication, and has used SI units in most of its publications.

Similarly, illumination engineers in the United States have worked with a hybrid system of SI units for basic illumination properties, and customary units for length, area, and compound units. SI units, such as the candela (cd), lumen (lm = cd·sr) and lumen per watt (lm/W) are already in general use, and the only significant changes needed would be the replacement of the lumen per square foot (lm/ft^2) with the lux (lx = lm/m^2), and the candela per square foot, lambert, and footlambert with the candela per square meter (cd/m^2). The change to SI units only, again, would simplify calculations and lighting design. The premier professional society for illumination engineers in North America, the Illuminating Engineering Society (IES), has decided to issue the eighth edition of its major reference document, the IES Lighting Handbook [1], with SI units as primary units and hard conversions. It is expected to be published late in 1980 or early in 1981.

While the change in units represents few complications, a "hard conversion" of electrical equipment and lighting fixtures and lamps would be more complicated and, in most instances, unwarranted. Should new sizes or designations be required as part of a "metric range," such ranges should be developed as new products rather than as conversions, aiming to reduce variety at the same time. For example, for electric motors, step increments of 0.5 kW in power output would yield fewer models than step increments of 0.5 hp (electrical) (0.373 kW). A 2-hp motor (1.492 kW) would be interchangeable with a 1.5 kW motor; similarly, a 4-hp motor [2.984 kW] would be interchangeable with a 3 kW motor, and in the intermediate steps of the range two metric sizes would replace three customary sizes, for an overall variety reduction of 25 percent. Fluorescent lamps in customary sizes are already too long for end-to-end installation of fixtures using the same nominal customary designations. For ceiling systems using metric modular dimensions such as 1200 mm, a new and shorter lamp of 1160 mm length would be needed. Major manufacturers have already conducted extensive research and trial production, but the "metric range" will take some time to emerge as 80 percent of all production goes into lamp replacement in existing customary fixtures.

Research into optimum metric sizes, as well as improved design (for example, the type of end pins used in fluorescent lamps) is regarded as a desirable part of the metric change which would best be carried out in the lead-time available before an M-Day and the commencement of orders for metric products.

6.4 HVAC—Heating, Cooling, Ventilating, and Air Conditioning

The design and integration of heating, cooling, ventilating, and air-conditioning systems in building is an area where the change to metric units and metric sizes has been viewed as being of little advantage while incurring some costs. However, many HVAC design engineers appreciate that coherent units and decimal relationships will facilitate calculations, as shown in 6.2.

The major advantage of the change to metric occurs in the use of one unit for pressure and stress, the pascal (Pa), and its decimal multiples, replacing such a variety of units as:

For pressure:	psf [lbf/ft^2]	=	47.88 Pa	
	inch H^2O (4°C)	=	249.0[illegible] Pa	
	foot H^2O (4°C)	=	2985.98 Pa =	[illegible].98 kPa
	inch Hg (0°C)	=	3386.38 Pa =	3.3[illegible] kPa
	inch Hg (60°F)	=	3376.85 Pa =	3.3[illegible] kPa
	psi [lbf/in^2]	=	6894.76 Pa =	6.895 kPa
	atmosphere (std)	=	101 325.00 Pa =	101.325 kPa
For stress:	psf [lbf/ft^2]	=	47.88 Pa	
	psi [lbf/in^2]	=	6894.76 Pa =	6.895 kPa
	tonf/ft^2	=	95 760.52 Pa =	95.761 kPa
	ksi [kip/in^2]	=	[6.894 76 x 10^6 Pa] =	6.895 MPa
			[13.789 51 10^6 Pa] =	13.790 MPa

A major professional society in this field, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) has been actively engaged in educating its membership on metric issues, and will have all its publications in dual units by 1981, including the Handbook series. During the transitional period, the ASHRAE Metric Committee will continue to disseminate educational material to prepare the membership for the eventual exclusive use of SI units.

Many of the major HVAC equipment manufacturers have subsidiaries or affiliated companies in metric countries, and have practical experience with production to metric standards and preferred sizes. It is likely that metric products would be introduced only when major redesign of product lines takes place, and that some items, such as pipes, would remain unaltered. The traditional size designations of pipes were, in most instances, nominal sizes, and the metric change would offer an opportunity to introduce standard designation of sizes, such as specification of internal diameter and thickness, which will automatically yield the external diameter.

6.5 Hydraulic Design and Plumbing

Hydraulic design is concerned with the flow of water and water-based substances into and out of buildings. It also includes surface water collection and drainage.

In metric units, hydraulic calculations would be simplified for a number of reasons:

1. For each physical quantity there is only one unit—especially for pressure;

2. Units are coherent, that is, they require no factors in going from one quantity to another, except decimal factors when going from a prefixed to a non-prefixed unit, another prefixed unit, or vice versa; and,

3. There is a direct relationship between the SI unit for volume, the cubic meter, and the common unit for capacity (liquid volume), the liter (L), where one cubic meter is equal to 1000 liters. (The conversion from cubic feet to gallons may be a difficult to remember conversion factor.)

Water pressure would no longer require a pressure unit of its own, but be expressed in pascals, or more commonly, kilopascals (kPa). For example, a head of water of 50 meters (50 m) represents a pressure of:

$50 \times 9.8^* = \underline{490\ kPa}$

[$50\ m^3/m^2 = 50\ 000\ kg/m^2 = 50\ 000 \times 9.8^*\ N/m^2 = 490\ 000\ N/m^2 = 490\ kN/m^2 = 490\ kPa$]

*In an absolute system, static head must be multiplied by gravitational acceleration [9.8 m/s^2] to give absolute force in newtons (N). The factor 9.8 is an approximation of the internationally standardized value of 9.806 65 m/s^2.

Derived calculations are also simplified by coherence between units. For example, if a pump is required to deliver a flow rate of five liters per second (5 L/s) at a pressure of 500 kilopascals (500 kPa), what pump power is required:

$5 \times 10^{-3} \times 500 \times 10^3 = [5\ \frac{m^3}{1000}/s \times 500\ 000\ N/m^2 = 2500\ N \cdot m/s = 2500\ J/s =$

$2500\ W = \underline{2.5\ kW}$ $\quad 2500\ W]$

The power of the pump motor, in kilowatts (kW), can be established directly if the transmission efficiency factor (in percent) is known. For example, the power with a transmission efficiency of 90 percent for the above pump would need to be 2500/0.9 W = 2778 W = 2.778 kW. A three kW motor would be suitable and have some spare power.

These calculations are very much simpler than those in customary units, because they are coherent units that follow the laws of physics directly. For a comparison, an example similar to the above would be: using flow rate in gallons per hour (gph), water pressure in feet (ft H_2O), pressure in pound-force per square inch (psi), power in foot pound-force per second (ft·lbf/s), and motor power in horsepower (hp).

Another significant advantage of metric units occurs in calculations involving drainage, run-off, or irrigation. Here, the decimal relationship of the liter (L) to the unit of volume, the cubic meter (m^3), provides significant shortcuts in calculations. For example, one millimeter of water distributed over an area of one square meter represents exactly one liter ($1\ mm \times 1\ m^2 = 1\ L$). This facilitates the calculation of gutters, channels, and downspouts for run-off. For example, the run-off from a roof with 200 square meters (200 m^2) of area and a rainfall of ten mm in five minutes (120 mm/h) will be: $10 \times 200 = \underline{2000\ L}$.

Remembering that one liter of water represents a cubic volume equal to that of a cube with 100 mm sides, the sizing of gutters and downspouts becomes much simpler than in customary units.

The same principles can be used in reverse: for example, in deciding on water requirements for irrigation or sprinkler systems. How much water is required to irrigate an area of one hectare (10 000 m^2) to the equivalent of five millimeters of precipitation? The answer is easy: 10 000 x 5 = 50 000 L.

As far as pipes and channels are concerned, it is not expected that new metric products will emerge rapidly; rather, as products are developed, they are likely to be developed in hard metric sizes. There is little reason for most domestic or commercial plumbing fixtures to change, except for their designation. Current sizes are rarely exactly those that are used for convenient designation. The exceptions are "built-in" units, such as baths, sinks, or shower bases, which should be related directly to the dimensions of building spaces into which they are to fit.

6.6 Acoustical Engineering

The science of acoustics uses metric equipment and metric units for laboratory and site measurement but in acoustic design the square foot for area and the cubic foot for volume are commonly applied.

The decibel (dB) is a dimensionless unit, or ratio, with a logarithmic base and it would not change. The reference quantities for sound power level (in watts), sound intensity level (in watts per square meter), and sound pressure level (in pascals), have always been in metric units.

The Acoustical Society of America (ASA) has presented technical information and standards in SI units for a number of years, and most acoustical engineers do not regard the change to metric measurement as a problem.

REFERENCE

1. IES Lighting Handbook, 6th Edition, Illuminating Engineering Society, New York, NY; (to be published in Winter of 80-81).

PART 7 – DEVELOPMENT AND RESEARCH ISSUES IN METRICATION

7.1 Investigation and Research

The metric conversion process can be described as an "applied research and developmental exercise" involving change; namely, the transition to the use of a different measurement system with different values in most processes of design, production and construction. In the case of the U.S. construction community, a better understanding of the issues involved in the change can be obtained by the examination and study of precedent in other countries and industries (investigation), and the indepth analysis of particular issues of industry-wide or sector concern (research). There may also be a need for the trial of alternative approaches (development) to find optimum technical solutions.

If no investigation, research, or development were to be carried out, time-consuming and costly errors might be made in the initial phases of a metric transition, and industry could be locked into suboptimal approaches by neglect. Further, unilateral actions or decisions in one area could adversely affect the operations of other segments. As the construction community represents a multi-disciplinary activity, involving both software (technical information, standards, drawings, etc.); and hardware (building products, materials, and built elements), it would be advantageous in most instances to conduct studies by means of multi-disciplinary groups representing all key viewpoints, except for very specialized and specific research topics. For example, "task forces" might be established by industry consent to study metric issues and concerns, and to report their findings to the industry at large. This would avoid a situation where decisions would be arrived at without considering both producers and users, for example, in the determination of optimum product size ranges.

7.2 Precedent and International Implications of Metric Conversion

A change to metric units would make the U.S. construction community part of the metric building world. This would have domestic as well as international implications. A thorough investigation of precedent in metrication in other English-speaking countries may provide shortcuts, give general guidance on how to deal with specific problem areas, and may point out which approaches are likely to lead to benefits for the construction community. It may also point out those which could lead to confusion and, therefore would best be avoided. An investment in "monitoring and evaluation" of metric developments and precedent, particularly in Canada, could be recouped many times over in savings of time and costs of conversion. It has been argued that the United States differs from other countries that have recently changed to metric units in the construction industry because of its geographic size, large population, giant industry turnover, special techniques, and particular form of building control. However, precedent is worth examining because design procedures, production processes, and construction techniques have become more and more similar the world over.

In a developmental sense, a change to metric units would make it more important to interact at the international level, particularly in standards development activities. This has been recognized in Section 6. (6) of the Metric Conversion Act of 1975, which deals with international consultation and cooperation.

The assessment of international standards in national standards-related activities is heavily promoted in Title IV of the Trade Agreements Act of 1979 [1], as is the intent to make U.S. viewpoints known at the international level. Section 402.(2) of the Act deals with the "Use of International Standards" and prescribes that "each Federal agency, in developing standards, shall take into consideration international standards and shall, if appropriate, base the standards on international standards." More significantly, the Act states in Section 403, on "State and Private Standards-Related Activities," that "It is the sense of the Congress that no State agency and no private person [defined to include any corporation, partnership, association, or other legal entity] should engage in any standards-related activity that creates unnecessary obstacles to the foreign commerce of the United States," and that "The President shall take such reasonable action as may be available to promote the observance by State agencies and private persons, in carrying out standards-related activities, of requirements equivalent to those imposed on Federal agencies under Section 402, and of procedures that provide for notification, participation, and publication with respect to such activities."

In the longer run, therefore, ignoring the existence of international proposals and standards could have serious consequences for U.S. industry and industry organizations whether in the provision of technical data or services outside or within the United States, or in the sale of products. As metric conversion offers a unique chance to harmonize domestic and international approaches, it is recommended that the implications of worldwide trends be studied fully, so that where appropriate, they can be taken advantage of should the construction community decide on conversion.

7.3 Basic Metric Issues

The fundamental issues in a change to another measurement system revolve around the selection of suitable units and numerical values which will maximize the opportunities that come with change and minimize any dislocation, confusion, and cost.

While ample information on good metric practice is already available, a number of aspects of unit use in building design have not been resolved. These require detailed study. Some examples of the topics which should be assessed are:

1. What metric units are to be used in the field of moisture (vapor) movement through building materials and condensation in building?

2. In thermal design, what could take the place of the degree day and traditional R-values?

3. Is there any need to replace the unit sabin in acoustical calculations, and, if so, with what form of unit?

4. What would be appropriate units to describe flow rates for a variety of applications, as well as in compound units, such as air infiltration, water consumption, etc.?

The major concern in metric conversion occurs in relation to the selection of "preferred" and "convenient" numerical values. Such values are important in a "hard conversion," that is, where a definite change is proposed. By comparison, a "soft conversion" simply requires reasonably rounded metric equivalents and, where possible, convenient values. Research studies would be desirable to identify:

a. A methodology for the presentation of dual unit statements in which a "hard conversion" can be distinguished from a "soft conversion" and which can be applied on an industry-wide basis.

b. General guidelines for conversion, rounding, and rationalization, with practical examples of "preferred values," number series, and variety reduction.

c. A classification system for building products according to the degree of conversion that would be required or desired, ranging from no change to extensive change.

7.4 User Studies to Determine Suitable Metric Design Dimensions

A change to preferred metric values in building would alter many of the traditionally accepted dimensions in building design and production; for example, a room height (floor-to-ceiling height) of 8 feet (2438 mm) could be replaced by a metric dimension of 2400 mm, which is 38 mm or 1-1/2" less; or, 2500 mm, which is 62 mm or 2-7/16" more. Examples of functional dimensions in building are numerous, such as clear heights, vertical clearances, horizontal clearances, minimum room widths, clear opening widths, height of work planes, height of guard rails, geometry of stairs and steps, design dimensions for the handicapped, etc. Studies which have led to "convenient" or "preferred" customary values should be reappraised to ascertain their validity in a metric context, and to determine whether metric preferred values would give equivalent safety, convenience, and economy, or whether user needs have changed. It is likely that such research would show that many customary values have been arrived at on the basis of numerical convenience rather than functional requirements, or by a mixture of the two.

A number of specific research studies are suggested for consideration:

1. Research into anthropometric factors of the American population, to give metric design guidance based on up-to-date statistical information on human dimensions of various profiles of the population such as children, adults, and the elderly, with differentiation of male and female dimensions and five percent, 50 percent, and 90 percent ranges. Most data now available were obtained many years ago, and it is possible that changes have occurred.

2. Research into human space needs (based on up-to-date anthropometric data) and the design of functional spaces, especially in dwellings, to determine whether minimum standards are appropriate and what "metric minimum standards" might be.

3. Research into the functional validity of width of egress dimensions (hallways, corridors, stairs, and exitways), based on 22" [559 mm] multiples, which have been used in many building code requirements. This research would show whether arithmetic or geometric progressions should be used in the selection of egress dimensions, and give guidance in the selection of the most suitable metric replacement values.

In addition, user studies might be expanded to take into account room areas and/or volumes.

7.5 Dimensional Coordination Research

Considerable research has been carried out in the United States and worldwide into the principles and practical application of a system of dimensional coordination in building. Broad agreements have been reached at the international level on a basic module of 100 mm and certain preferred multiples for building and building product dimensions. However, international preferences do not include the metric equivalent of the traditional U.S. dimension of 16 inches (406 mm) or 4 modules—400 mm—as a direct multimodular preference. It is probable that U.S. recommendations for metric dimensional coordination would be somewhat different from international recommendations.

A number of research projects are needed to deal with specific aspects of (metric) dimensional coordination, such as:

1. What will be the impact of the 100 mm module, as a substitute for the 4-inch module, on building design and design standards; building codes and minimum requirements; building products and manufacturing processes; and, on-site layout and assembly processes?

2. What would be the optimum dimensions for functional spaces and spans in buildings, based on the 100 mm module? Where could traditional

recommendations be reduced and where could they be enlarged advantageously? Where can changes arising from energy considerations be coupled with changes resulting from or required by metrication?

3. How could product ranges be rationalized, using preferred (modular) sizes as basic sizes, and non-preferred sizes as special sizes?

4. What would be the economics of dimensionally coordinated (modular) design versus non-coordinated design? Would metric units and preferences facilitate computer design and documentation (or, does the computer facilitate coordinated design)?

5. What would be the economics of producing dimensionally rationalized products? Could the overall product range be reduced without a loss of sales? What would be the advantages and disadvantages in distribution and transportation? Is there scope for improved modular packaging?

6. What would be the costs and benefits of metric construction layout and assembly, using dimensional coordination principles and coordinated products? Would improved construction accuracy result?

7. What reeducation and training would be required to increase the use of dimensional coordination in the construction industries?

While the investigation of these aspects of (metric) dimensional coordination would have to rely on the judgment and opinions of people involved in design, production, and construction, it is important that any research studies undertaken involve the actual designers and builders to yield the most useful results. It may be worthwhile to use correlating groups of people who have been involved in the application of (metric) dimensional coordination and those who have not, to ascertain differences in opinions.

7.6 Investigation of Design and Documentation Aspects

The change to SI units would require the revision of almost all technical data and standards used in building design. In a transition, three approaches could be used to deal with technical information:

1. the conversion of existing data and design aids;

2. the conversion and rationalization of existing data and design aids; and,

3. the development of entirely new technical data and design aids.

Investigative effort and research studies should be aimed at the identification of technical data needs in the design process so that priorities for conversion could be allocated. Unless design data and aids are available in time for metric project design, considerable professional and technical efforts might have to be spent in developing data on a project-by-project basis, which could adversely affect the economics of metric design. Many of the design aids now in use have been developed with particular reference to U.S. customary (inch-pound) units to facilitate decision-making; for example, tables, charts, monograms, etc. Some of these would no longer be required because of the coherence of units in SI; however, others would need to be revised or amended. There is ample scope for the simplification of design data and design aids in metric units, especially in energy design information where fewer and coherent units would be used.

7.7 Investigation of Building Codes and Standards

A special aspect of the review of technical data during a conversion would be the need to develop metric versions of building codes, related design codes, and building standards. It is widely agreed, and generally supported by the findings of the U.S. Metric Study and the GAO Metric Study, that simplification and harmonization of American building codes would be a major opportunity in a change to SI, which could yield long-term benefits to the construction community. Therefore, a major research effort should be aimed at "opportunities for improving building codes and standards during metrication." In the GAO Metric Study, associations representing codes and standards organizations, labor, distributors, contractors, and designers all agreed that conversion would provide such an opportunity.

Rather than aiming metric investigations and research efforts over the broad spectrum of building codes and standards, selected areas of concern or opportunity might be isolated and studied in-depth to develop optimum metric recommendations.

Among the topics that merit detailed analysis would be:

1. Units and preferred values for loads and forces acting on buildings, such as live loads, dead loads, wind loads, snow loads, seismic forces, etc., based upon up-to-date data.

2. The research-based development of (metric) performance requirements for building elements and the building environment, with particular reference to international standards or proposals in this area.

3. The research-based dev .opment of (metric) compliance tests for building elements, products, and systems, taking note of international recommendations and standards.

7.8 Investigations into Building Products and Production Processes

Metrication implies "review," though not necessarily wholesale change of customary products (sizes), processes, and procedures, with a view to obtaining more cost-effective and functionally efficient metric alternatives.

Many products need not be changed, as they require modification within present production tolerances only because existing standard (or specified) sizes convert to convenient metric dimensions. Only where dimensional coordination impacts would it be reasonable to make changes. The research and developmental decisions facing producers and producing sectors revolve around rationalization of construction product lines, that is, the possible replacement of existing ranges with smaller or functionally superior metric ranges. Research into optimization proposals requires an assessment of all processes from the raw materials stage to the consumer. The development of a production/distribution/use model for products or product groups may yield many useful data for rationalization.

It has been pointed out that the rationalization of product lines is an opportunity that exists at any point in time. However, without a far-reaching industry-wide change--such as a change to metric measurement--there is no strong catalyst for change. It is also possible that proposals would be hampered by actions in the marketplace, with opposition from interest groups and competing manufacturing interests. The lumber industry provides an insight into the difficulty of "change" without an external cause such as metrication. In 1970, the industry went through a major and controversial change in softwood lumber sizes, grading standards, and engineering design values, which represented something akin to a "hard conversion." The project required many years of inter-industry meetings, hearings, technical and engineering discussions, and research and developmental activities. The lessons were that research, early planning, and good communication are essential to a smooth change. Based on this preparation, the actual changeover went smoothly, quickly, and easily for manufacturers, distributors, and users, despite some minor concerns in the marketplace.

Industry associations are in a key position to play a prominent role in "research and developmental" activities such as:

1. the determination of optimum sizes for products based on manufacturing and user requirements;

2. the assessment of the impact on standards and standard details, energy use, and end-use productivity;

3. the development and distribution of technical information to facilitate conversion and familiarization; and,

4. the consideration of industry-wide aspects of timing for the change.

The experience of similar industry groups in metrication, notably that of Canadian industry, may provide significant guidance in these activities. (For example, the Canadian steel industry is now producing some of the products and sizes likely to emerge in the United States if metric demand increases.) These research activities would be desirable, regardless of specific target dates for conversion, as the lead-time required to harness "opportunities" is seldom long enough.

It is recommended that investigations be centered on "productivity," including warehousing and distribution as well as manufacture. Often the costs of inventory-holding are a major factor in construction product cost, and sometimes they determine the difference between profit or loss from operations. Productive metrication not only means streamlining product lines and processes, but minimizing "dual" production runs and "dual" inventories. Again, the study of precedent may yield useful guidance on how to minimize the costs and disruption, if any, resulting from duality. Precedents in "catalog optimization research" are found in "metric fasteners" and "metric reinforcing steel," and the approaches taken in these segments of the metals industry may provide useful models for other industry segments.

7.9 Investigation of Metrication in Construction and Maintenance

The role of the contracting industry in metrication has been described as a passive one in the early stages of conversion, until such time as designers begin to prepare metric documentation and producers gear up for metric production. This assessment ignores the significance of measurement-based operations on construction productivity. The use of decimal measurement to replace the variety of units now in use would facilitate estimating, layout, purchasing decisions, and general on-site construction activity.

Ideally, investigations should have commenced to identify all areas where improvements in on-site operations might be affected in tandem with a conversion; for example, in layout, use of materials, positioning and assembly of components, and maintenance of construction accuracy.

Specific areas for investigation and research might be:

1. What are the most common causes of on-site error or inaccuracy in current construction, and are there opportunities to avoid such occurrences in metric construction by altering techniques of measurement or assembly?

2. How can metric dimensional coordination be facilitated in construction? What techniques might be used, altered, or developed? What equipment is essential, and what is helpful?

3. What training or familiarization of site personnel is required? What types of training aids and documents are needed?

The role of construction unions in metric research has primarily been related to the concern that construction personnel might not be able to cope with metric work unless given extensive training, as well as assistance with the replacement of tools. The investigation of experiences in other sectors of the economy (such as the automotive industry), and other countries (particularly, Canada) would be useful to determine the extent of these problems. Some reports dealing with actual metric work experience in other countries stress that construction personnel, once involved in metric operations, prefer to remain with metric units and not switch back to customary units thereafter.

Some concern has been expressed by designers and building owners about the potential difficulties associated with the repair and maintenance of "non-metric" buildings and plant. No direct research evidence is available of either increased costs or specific difficulties encountered in other countries in the field of building maintenance and rehabilitation. The repair and rehabilitation industry has developed an ingenious capacity to deal with situations involving non-availability of materials and parts, and many lessons can be learned from current practices in non-metric units. The entire subject area represents a major "applied" research project.

7.10 Adaptation of Materials During A Transitional Period

A similar aspect of a change to metric measurement would be the adaptation of building products and materials during the transitional period. First, that of customary sizes to fit with metric building designs and, second, that of metric sizes to fit with non-metric building designs. Both would occur. The advantage of new construction work is that decisions can be made, or amended, before the building is irretrievably constructed. For example, if the size of reinforcing steel should change to new metric sizes during the construction life of a project, a design check and, possibly, some minor changes in spacing may be needed. If, however, a building designed in customary units is to be built at the end of the transitional period, some customary products may no longer be available, and metric products would need to be adapted. Other industries have coped successfully with such a transition, so that there is no reason to suspect that the U.S. construction community would be unable to do so. It would be desirable to undertake investigations early so as to identify and analyze areas where "adaptation problems" might arise.

7.11 Research Into Legal Implications, Contracts, and Agreements

While the metric system, by public law, has been permitted to be used in the United States for over a century, there are many existing statutes, regulations, and ordinances which state requirements expressed exclusively in U.S. customary units. Such laws or regulations could provide barriers to the selection and use of alternative, "hard converted" (preferred) metric values, especially, if they establish minimum or maximum acceptance levels that would preclude the choice of a preferred metric alternative.

For example, a minimum requirement of 4 feet (1219 mm) would preclude the use of a modular preference of 1200 mm, or a maximum pressure of 250 lbf/ft^2 (11.97 kPa) would preclude the use of a preferred 12 kPa as design criterion.

The identification of critical laws or regulations which have a measurement impact on design, production, and construction represents a major task. Within this task, there is the research activity of determining any critical values or requirements that might inhibit the use of "hard metric" alternatives, necessitating a study of the basis of traditional measurement values and their amenity to change.

Another research area involves the implications of product unavailability and substitution, including methods of compensation for extra costs, if any, of obtaining specified products. Substitutions, as well as extras, have always been a feature of construction contracts, and safeguards would need to be established to ensure that neither the contractor, nor the building client becomes the victim of "metric" costs that were avoidable either by design decisions or by purchasing decisions. A special metric contract clause may be desired during a transitional period.

Labor agreements and awards contain some measurement-related clauses, and these would need to be identified. In some instances, they may need to be amended to coincide with a new measurement environment. In general, a change should neither reduce awards nor increase labor costs, so that a conversion would need to be effected within a fair and equivalent range. However, a give-and-take approach may prove to be more economical in the longer run, and alternatives should be researched by employer as well as employee groups, preferably by a joint task force.

7.12 Research and Development in Perspective

It has been suggested by metric experts in other countries that have completed the change to SI that metrication represents one of the greatest "review" opportunities of modern times—no established value, benchmark, or practice is sacrosanct! However, judicious management is required to prevent metrication from becoming the greatest "research exercise" of modern times, with industries and organizations waiting for the results of research before embarking on any change.

A change to SI represents an opportunity to analyze traditional approaches and their validity in a modern technological environment. The opportunity to change to preferred values and rationalized ranges must be duly considered, if greater economy and productivity is to result from such change. It is in this area that thorough research rather than superficial assessments will be needed.

The entire construction community can perform a major role by developing a coordinated list of worthwhile metric research projects, so that the research resources available to the industry can be harnessed and used wisely.

REFERENCE

1. Trade Agreements Act of 1979, Statements of Administrative Action, House Document No. 96-153, Part ii, 96th Congress; U.S. Government Printing Office, Washington, D.C.; 1979; Title IV-pp. 211-233.

PART 8 - TIMING OF METRIC CONVERSION IN THE CONSTRUCTION INDUSTRIES--AN ASSESSMENT OF CRITICAL ACTIVITY ITEMS

8.1 Key Features of a Timetable for Conversion

A timetable for conversion should show "what needs to be done" (the key action items in conversion), "when it should be done (a time frame for accomplishment), and "who is principally responsible for it" (the lead group for the accomplishment of an activity, and others affected).

In the United States there is no formal national commitment to metric conversion or a national time frame for the change. It is left to individual sectors and industries to determine whether or not to convert, when to convert, and in what mode to convert (soft vs. hard conversion).

The Construction Industries Coordinating Committee (CICC) of the American National Metric Council (ANMC) has examined metric issues and developed a plan for voluntary conversion. The plan includes a "Construction Industries Metric Conversion Timetable."

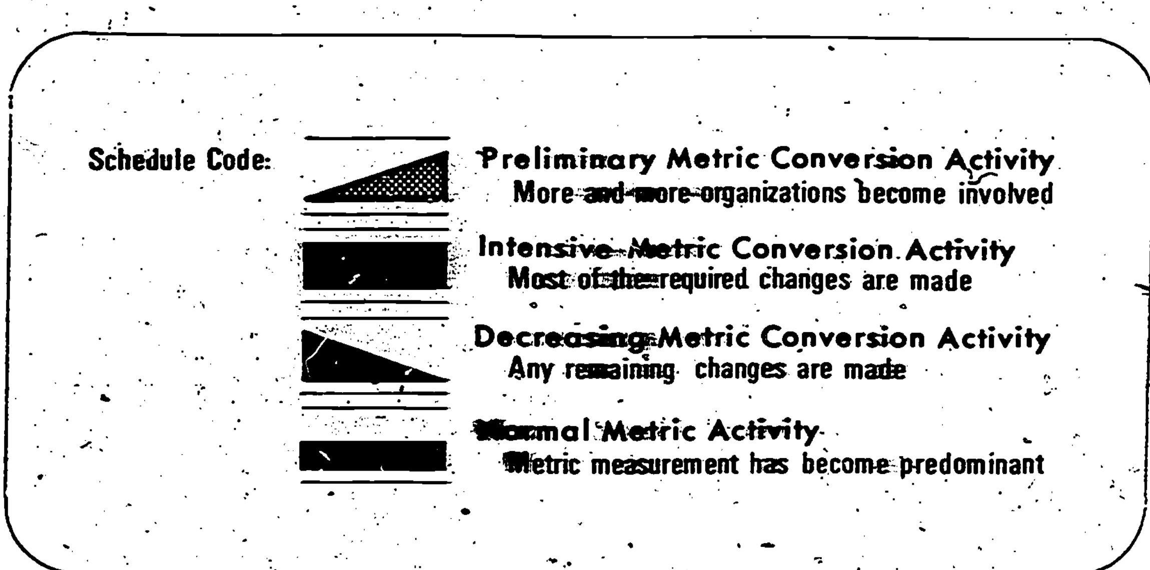
This timetable, shown in Part 1 (figure 1-1), goes beyond the timetables developed in other countries, by indicating which sectors would have a "lead role," as well as which other sectors would be involved in each action item. This allows industry sectors, associations, and individual organizations to plan specific and general responses, and to concentrate on those areas where they would be primarily involved.

The ANMC/CICC Construction Industries Metric Conversion Timetable represents an attempt by private sector groups to develop a schedule for a voluntary conversion, in the construction industries. The timetable is the outcome of lengthy investigation and planning activities, and has been submitted for public scrutiny and comment. Like any timetable, it is a "best guess" of the time scale necessary for conversion by people familiar with industry activities who have also studied relevant metric issues. As it provides time periods for each activity item, it would allow both early and late starts in actual implementation, but within a framework of relationships to other program items.

The timetable shows a series of calendar years during which conversion activity would take place. It also uses the concept of an "M-Day" as a focal reference point in time to signify the key event(s) in the industry; namely, the change from customary units to metric units in the production of materials and the construction of buildings. The M-Day is the threshold in the program where hardware in metric sizes will become available, and it can be likened to "noon" as a point in time which divides "ante" (a.m.) from "post" (p.m.). An industry-agreed M-Day would simplify metric management decisions--at any particular date there is a clear indication of lead-time left to the point of transition.

In practice, conversion activities in a sector would take place over periods of time, rather than instantaneously. Individual organizations would probably phase in their changeover when the time for conversion is at an optimum. Some organizations may attempt to start early, others may wait until the bulk of the industry has converted. This means that each action item will have a "transition period" of some ... may amount up to a number of years. The timetable uses a grap... method to illustrate "phases" in the change.

Figure 8-1: Graphical Illustratic ... "Phases" in a Change



An understanding of the timetable and its intention is of great importance.

As part of the planning process, ANMC/CICC prepared supplementary metric conversion schedules, or timetables, for individual sectors. The supplementary schedules amplify certain items but are otherwise in full agreement. Full details are contained in ANMC publication "Metric Conversion in the Construction Industries—Planning, Coordination, and Timing" [1].

8.2 Action Items in the ANMC Construction Industries Metric Conversion Timetable

The ANMC/CICC Construction Industries Metric Conversion Timetable, shown in figure 1-1, lists 23 action items. An understanding of the meaning and general intent of these action items is desirable to ensure the best phasing corporate research, developmental, production, and educational activities in compliance with industry-agreed time phases. No specific description of the scope of individual action items in the timetable has been provided by ANMC/CICC, although more detailed subdivisions of action items are given in activity descriptions prepared by the individual CICC Sectors. These activity descriptions have been relied upon in the discussion of the technical content or scope of each action item.

8.2.1 Publish Metric Practice Guide for Construction (and Revise)

Preliminary Phase:	1978/79
Intensive Phase:	1980/81
Residual Phase:	1982

A metric practice guide is the major technical "desk reference document" for the transitional period. It is intended to provide technically correct information on conversion approaches and procedures, including the selection of preferred values (rationalization) and rules for writing and documentation (drawing practice) in metric (SI) units. Supplementary metric practice guides for specific sectors and subsectors would be based on the general metric practice guide for construction.

While no comprehensive metric practice guide for the building community has been prepared, parts of metric practice guides have emerged through national standards-generating organizations with broad general agreement on rules and recommendations. Some such organizations are the American Society for Testing and Materials (ASTM), American Society of Mechanical Engineers (ASME), American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Institute of Electrical and Electronic Engineers (IEEE), and Illuminating Engineering Society (IES). The most comprehensive document on the use of SI units currently available to the industry is the ANSI/ASTM Standard E621-78, "Standard Practice for the Use of Metric (SI) Units in Building Design and Construction" [2].

Another reference document which provides a comprehensive set of metric practice guidelines is the "AIA Metric Building and Construction Guide" [3].

8.2.2 Develop Necessary Basic Metric Standards

Preliminary Phase:	1978/Mid-1979
Intensive Phase:	Mid-1979/1981
Residual Phase:	1982/Mid-1983

The task of establishment of standards objectives, identification of new standards needed and existing standards requiring conversion, as well as the overview of the development of basic metric standards required in the construction community (including priorities for development or conversion), is a key function of the Construction Codes and Standards Sector, the most active Sector in ANMC/CICC. The Sector and its Subsectors are involved in the standards identification phase, although a varying degree of conversion and rationalization activity is taking place in most national standards-generating organizations.

Key standards include documents dealing with design loads; structural design in concrete, steel, masonry, and timber; dimensional coordination of buildings, building materials, and systems; building services design concepts (HVAC, electrical, illumination, plumbing, etc.); performance aspects of major building materials or components; design for special occupancies (handicapped, elderly, children, etc.); and, space standards for building occupants, equipment, and vehicles.

8.2.3 Determine Product Sizes in Metric Units
Preliminary Phase: 1978/Mid-1980
Intensive Phase: Mid-1980/1984
Residual Phase: 1985—ongoing as normal metric activity

The determination of metric product sizes is a prerequisite to the production of genuine metric materials, components, and systems. The process of deciding on suitable and preferred sizes involves inter-industry meetings and discussions, the preparation of draft proposals and draft standards, and the finalization of metric product standards.

Considerable effort already has been undertaken in determining product sizes for steel products, reinforcing materials, masonry units, building lumber, and glass. More detail on this is given in Part 5. The existence of dimensional preferences, outlined in Part 6, will assist industry sectors to arrive at preferred metric product sizes and ranges.

8.2.4 Produce Metric Measuring Equipment
Preliminary Phase: Mid-1979/1980
Intensive Phase: 1981/1984 (inclusive)
Residual Phase: 1985—ongoing as normal metric activity

This action item is shown in seventh place in the ANMC/CICC Timetable, but chronologically and logically might be shown earlier to maintain the internal sequence and relationships of the timetable. For this reason, it is discussed at this point.

Metric measuring equipment will be needed for design and documentation, production (including research, development, and testing), and on-site construction. The equipment involved ranges from simple scales for mass (weight), gauges for measurement of pressure or stress, and thermometric devices. A wide range of equipment in metric (SI) units is already available and used in laboratory and other work, in other, partially metric industries, and in the Canadian marketplace. As with construction products, it is desirable to develop national standards for metric measuring equipment which include the use of correct units, suitable graduation or scales or dials, and tests for accuracy of the measuring device.

8.2.5 Decision to Build Metric Building
Preliminary Phase: 1980/Mid-1981
Intensive Phase: Mid-1981/1984
Residual Phase: 1985—ongoing as a normal metric action

The accomplishment of conversion is dependent upon decisions by clients to build metric buildings in accordance with an industry-agreed timetable. Clients need to be assured that a metric building will not incur additional construction costs or time. The building decision, to a large extent, guarantees metric demand, although a point in time will be reached in the transitional period where non-metric construction could create a degree of premature obsolescence in a building and, thus, might not be in the best interest of the building client. It would be expected that most new construction after the M-Day would be carried out in metric measurement, as would all new design.

8.2.6 Award Design Contract [for Metric Design]

Preliminary Phase: 1981/Mid-1982
Intensive Phase: Mid-1982/1985
Residual Phase: 1986--ongoing as normal metric activity

This timetable action item is a logical extension of a decision to build a metric building, and has a one-year displacement in the schedule. Of course, design contracts for metric buildings outside the United States have been awarded to U.S. design organizations for some time. However, this item would relate specifically to design work within the United States.

8.2.7 Begin Conceptual Design in Metric

Preliminary Phase: 1981
Intensive Phase: 1982/1985
Residual Phase: 1986--ongoing as normal metric activity

This action item is shown in eighth place in the ANMC/CICC Timetable, but chronologically and logically follows the award of the design contract for a metric building, particularly, as the timescale provides for substantially the same durations. Conceptual design in metric units is dependent upon the availability of key reference documents setting out space requirements and acceptable (minimum) standards for activity areas and accessibility in metric dimensions. Conceptual design will also be aided by agreed dimensional coordination guidelines.

8.2.8 Develop and Distribute Metric Product Literature

Preliminary Phase: Mid-1980/Mid-1981
Intensive Phase: Mid-1981/1985
Residual Phase: 1986--ongoing as normal metric activity

While shown in sixth place in the ANMC/CICC Timetable, this action item is highly dependent upon the determination of product sizes in metric units (8.2.3) and decisions by industry segments or individual companies to market or foreshadow metric products. (A number of metric roofing products are already available, as indicated in 5.9.) Some metric product information may also have been developed for external markets, such as Canada.

In some instances, one product line with two sets of product literature may be all that is needed to accomplish conversion, and the steel industry provides some useful precedent with the description of steel sections and shapes in both U.S. customary units and metric units. In other product groups, product literature needs to be distinguished clearly and carefully to differentiate between non-metric and metric products. During a transitional period, product literature will be a major source of technical information, and it is important that it be developed in correct SI units and with correct presentation of symbols and numbers. Metric catalogs and listings of metric product literature probably should be stored separately from other data for easy access and retrieval.

8.2.9 Publish Model Codes in Metric
Preliminary Phase: Mid-1980/1981
Intensive Phase: 1982/1984
Residual Phase: 1985--ongoing as normal metric activity

Metric units in model codes can take the form of dual values, either as direct equivalents or as alternative values, or a metric supplement (as used initially in the National Building Code of Canada), or as a separate metric edition. Each approach has some advantages and some drawbacks. In general, the further the change has advanced, the more need there is to incorporate preferred metric values.

One of the strategies for a smooth transition is to work towards a "hard" metric version in successive editions. This can be accomplished by selecting convenient alternative metric values in all cases where full interchangeability is not required and where no industry standards have been drafted or issued. However, it should be done with the proviso that any metric values shown can only be used with metric documentation and cannot be reconverted to U.S. customary units to obtain a more advantageous compliance value. In this manner both customary and metric preferred dimensions can be accommodated in one document. This approach would eliminate many "nuisance values" from model codes and subsequent statutory documents based upon them.

8.2.10 Enact Enabling Legislation [for Metric Requirements]
Preliminary Phase: Mid-1980/1981
Intensive Phase: 1982/Mid-1983
Residual Phase: Mid-1983/1984

This action item is shown in eleventh place in the ANMC/CICC Timetable, but chronologically and logically might be shown directly after the publication of model codes, as it is designed to provide the legal basis for the enactment of metric (building) requirements. The enabling legislation need not indicate specific values in either measurement system, but rather prescribe the maximum extent of permissible modification to requirements to facilitate their acceptance at state or local government levels. The enactment might also stipulate certain dates for acceptance of documents submitted entirely in metric units and, possibly, a target date after which metric documents will be preferred.

8.2.11 Conduct Land Transactions in Metric
Preliminary Phase: Mid-1980/1981
Intensive Phase: 1982/1983 (inclusive)
Residual Phase: 1984—ongoing as normal metric activity

This action item is shown in twelfth place in the ANMC/CICC Timetable, but might be shown directly after the enactment of enabling legislation, as such legislation may be required before land transactions and registration can take place in metric units. Precedent has indicated that the least expensive transition is accomplished if land transactions are recorded and titles issued in metric units only on an ongoing basis so that the additional cost, if any, is marginal. Again, for effective operations, target dates should be set at the local level to minimize transitional difficulties.

8.2.12 Produce Property Surveys in Metric Units
Preliminary Phase: Mid-1980/1981
Intensive Phase: 1982/Mid-1984
Residual Phase: Mid-1984/1985—ongoing as normal metric activity

This timetable item is closely related to the conduct of land transactions in metric units. Metric surveying equipment is already available, and the surveying and mapping community has developed a practice guide for metric activities [4]. At the national level, topographical quadrangle maps with ratio scales and metric contour elevations have been published by the U.S. Geological Survey in cooperation with several states, and state plan coordinate systems are being adapted to SI with the assistance of the National Geodetic Survey of the National Oceanic and Atmospheric Administration (NOAA).

8.2.13 Develop Metric Estimating System
Preliminary Phase: Mid-1980/1981
Intensive Phase: 1982/1984 (inclusive)
Residual Phase: 1985

The development of a metric estimating system in building is shown as the tenth item in the ANMC/CICC Timetable, but might be shown in a later action item, since it represents the first activity in which the contracting community will become involved significantly as a "lead" sector. The coherent relationships between SI units and metric dimensional coordination should facilitate the development and maintenance of a metric estimating data bank, and thus assist contractors, designers, producers, and users. The preliminary phase might be used to develop suitable computer programs.

8.2.14 Begin Design Development and Engineering in Metric
Preliminary Phase: 1982/Mid-1983
Intensive Phase: Mid-1983/1985
Residual Phase: 1986—ongoing as normal metric activity

The development of detailed architectural designs and engineering calculations in metric units represents the first major commitment to a metric mode of building. Design development and engineering are somewhat dependent upon the availability of standards and product information, as well as general agreements on metric product availability. The objective of metric design should be to minimize the amount of new non-metric construction after the construction industry M-Day—that is, if the design is expected to go into the field in 1985, or thereafter, it would be advisable to use metric (SI) units.

8.2.15 <u>Estimate and Bid on Metric Documents</u>
Preliminary Phase: 1983
Intensive Phase: 1984/1985
Residual Phase: 1986—ongoing as normal metric activity.

If the ANMC/CICC Timetable is adopted by the construction community, construction contractors are likely to be faced with metric documents from 1983 onwards. This represents the first test for the metric estimating system developed by contractors and subcontractors. Whereas bidding on early projects may be more difficult than competing for nonmetric work, it will build up metric judgment and expertise and is likely to pay dividends later when major clients will look for organizations with proven metric capability.

8.2.16 <u>Award Metric Construction Contract</u>
Preliminary Phase: 1983
Intensive Phase: 1984/1985
Residual Phase: 1986—ongoing as normal metric activity.

The award of a metric construction contract represents the second major commitment to a metric mode of building. It will give a building client a structure with minimum built-in obsolescence, compared with a non-metric building carried out at the same time. The construction contract needs to include safeguards for all parties in the event of unforeseen difficulties. It would be unreasonable to hold the contractor responsible for all non-availabilities; similarly; it would be unreasonable to have the client pay for substitutions or extra work that could clearly have been avoided. Precedent has indicated that early metric jobs are generally better planned and managed to avoid pitfalls; therefore, "extras" are less rather than more likely to occur.

8.2.17 <u>Accept Plans in Metric and Issue Building Permits</u>
Preliminary Phase: Mid-1983/1984
Intensive Phase: 1984/1985
Residual Phase: 1986—ongoing as normal metric activity

Metric construction activity cannot eventuate without approval of metric plans and the issuance of a building permit. Ideally, plan approval should be based on statewide or regional agreements and target dates to minimize disruption.

8.2.18 Obtain Labor Agreements in Metric

Preliminary Phase: Mid-1983/End-1983
Intensive Phase: 1984/Mid-1985
Residual Phase: Mid-1985/End-1985

The identification of measurement sensitive labor agreements and their review and restatement in sensible metric terms is one of the shorter activity items in the ANMC/CICC Timetable. It should be fully accomplished within a period of one year from the proposed M-Day.

8.2.19 Begin Construction of Metric Buildings

Preliminary Phase: 1984
Intensive Phase: 1985/Mid-1986
Residual Phase: Mid-1986/1987—ongoing as normal metric activity

This action item has been shown in a heavier outline as it represents the focal item in the Timetable—namely, the transition to the use and assembly of metric hardware. It is closely allied to the production and delivery of fully metric building materials and components.

It is anticipated that some trial or pilot projects will be commenced prior to the designated industry M-Day, and that metric construction will accelerate rapidly thereafter. Within two years from M-Day, all new projects should be constructed in metric units as a normal mode of operation to minimize the duration of the transitional period, and dual production lines, dual inventories, etc. Metric training of construction personnel can be undertaken either on the job, or immediately preceding the involvement in metric tasks.

8.2.20 Deliver Metric Products to Suppliers and Site

Preliminary Phase: Mid-1984/End-1984
Intensive Phase: 1985/1986
Residual Phase: 1987—ongoing as normal metric activity

This action item is sequential to the production of metric materials and components, and shows general overlap with metric construction activity. The availability of metric products will determine the ease with which metric construction can proceed. A suitable identification system is required to differentiate metric and non-metric products in the transitional period.

8.2.21 Complete Metric Construction

Preliminary Phase: 1985
Intensive Phase: 1986/Mid-1987
Residual Phase: Mid-1987/1988—ongoing as normal metric activity

At first sight, this action item seems superfluous, especially as with its accomplishment the point will be reached where all new construction is carried out in metric units. However, the timescale shown indicates a lag time of one year between activity items 19 and 21 (begin metric construction and complete metric construction), which may be taken as an approximation of "average" construction duration. Individual targets for commencement and completion of metric construction have to be set for each project, and the inclusion of this action item serves as a reminder that the completion date is just as important as the commencement date.

8.2.22 Occupy and Maintain Metric Buildings
Preliminary Phase: 1986/Mid-1987
Intensive Phase: Mid-1987/1988
Residual Phase: 1989--ongoing as normal metric activity

The occupancy and maintenance of "metric" buildings signifies the accomplishment of the changeover. Apart from any clearance or loading signs there will be few direct reminders that a building is a metric building. Maintenance should be easier as general repair or maintenance items in metric sizes increasingly will become available.

8.2.23 Conduct Real Estate Transactions in Metric
Preliminary Phase: Mid-1986/Mid-1987
Intensive Phase: Mid-1987/1988
Residual Phase: 1989--ongoing as normal metric activity

The ANMC/CICC Timetable envisages that real estate activities in metric units will follow rather than run in parallel to metric conversion in the construction industries. To a large extent, the change in real estate is a change in the descriptions only (that is, the software), which can be accommodated by means of a soft conversion and/or dual units during a transitional period until such time as estate agents, sellers, and purchasers become familiar with metric units.

8.3 Some Comments on the ANMC/CICC Construction Industries Metric Conversion Timetable

The ANMC/CICC Construction Industries Metric Conversion Timetable is complemented by a number of Sector timetables which show greater detail in the action items. They include periods for familiarization or training of construction industry professionals, technicians, site personnel and labor; and office staff; research and developmental activities; and, generally, an expansion of items relevant to the particular Sector.

It is significant that in the review of the ANMC/CICC Timetable by committees, individuals, and representatives of industry groups, there seems to have been no concern about the format or the chronology of the timetable. However, metric planners have stressed the need for an "industry commitment date," which would represent an agreement by the bulk of the construction community to participate in a voluntary but coordinated change, based on an agreed timetable, so that individual entities can each play their parts to effect the change in the best interests of the whole industry and, especially, its clients.

The ANMC/CICC Timetable with its well-structured chronology of "action" items and an indication of leadership responsibilities, is a practical reminder of the need for "cooperation" between all sectors. Its focal point, relative to which elasped times and targets can be measured, is the "industry M-Day"—a conceptual date indicating the start of metric construction. The commitment in a timetable is not to specific dates, but rather to phases or periods during which certain actions are expected to occur. The individual industry segment, group, or organization, therefore, can phase into the overall time scale as and when it is most advantageous from a technical and/or economic point of view.

8.4 International Precedent in Construction Metrication and Program Timing

Table 8-1 provides a summary of the approaches and time factors in metric conversion in the construction industries of Britain, South Africa, Australia, and Canada. Even though industry size and structure differ from the United States, the respective approaches and accomplishments are of interest. Metric planning, as a management exercise with technical overtones, was basically the same in all countries, with each nation except Britain learning from the precedent of others. In general, a period of 3 to 4 years to M-Day was found to be adequate to carry out the key activities and, at the same time, maintain momentum.

8.5 A Model for the Achievement of a Decision on Construction Metrication

Responses to metrication vary from "let's stop talking and get it over and done with" to "let's defer it until there is an absolute necessity to change," with the bulk of the industry covering a middle ground of willingness to convert "if everyone else does." In the construction community, the strongest advocacy has come from designers, who can foresee significant gains in productivity, and the codes and standards sector, in which designers are heavily represented as professional decision-makers. Both groups deal almost exclusively with "software." Except for certain groups which can see very tangible benefits in a change, manufacturers, distributors, contractors, and labor have preferred to defer a commitment.

It is widely recognized that the construction community cannot accomplish a definite response to the metric issue without cooperation and involvement of the key sectors and major parties that make up the industry. The principal purpose of the NIBS Metric Symposium is to provide a forum for the "objective" examination of metric issues in the construction industries—without letting those in favor or those opposed dominate—and then to develop suitable industry-wide strategies for future action.

Unlike other activities in the construction industry, metric conversion is not an oft repeated activity which can be precisely designed, accurately estimated in terms of cost or time, and carried out as a matter of routine. It is the most difficult assignment the industry has faced for a long time. It is an assignment that cannot be faced unilaterally by individual sectors of the construction community, but rather needs to be undertaken by all or

Table 8-1: International Precedent in Metrication in Construction--Comparison of Program Timing

COUNTRY	METRIC PLANNING OR COORDINATING COMMITTEE (Date Established)	FIRST YEAR SHOWN IN THE OFFICIAL METRIC PROGRAM	M-DAY OR START OF METRIC CONSTRUCTION	TIME TO M-DAY (Years)	PROGRAM COMPLETION DATE	TOTAL CONVERSION PERIOD	REMARKS
BRITAIN	Construction Industry Metric Panel (British Standards Institution), May 1965 Steering Committee for Industrial Materials and Construction (Metrication Board), June 1969	1966 Program Available February 1967	From January 1970 (No M-Day)	4 Years	Estimated: End of 1972 Actual: End of 1974	7 Years (9 Years)	Conversion was hindered by a lack of organization and an absence of metric conversion activity in the general economy. Metrication was combined with dimensional coordination.
SOUTH AFRICA	Industrial Metrication Division, Metrication Department (South African Bureau of Standards), during 1968. Metrication Advisory Board established 1967	1969	From January 1, 1972 (Subsequently Advanced to July 1, 1971) (No M-Day)	3 Years (2-1/2 Years)	End of 1973	5 Years	Metric implementation took place simultaneously throughout the entire economy. Target for metric construction was advanced by 6 months to sustain momentum. Dimensional coordination was not mandated.
AUSTRALIA	Building and Construction Advisory Committee (Metric Conversion Board), November 1970	1971	January 1, 1974	3 Years	End of 1976	6 Years	Program completed within the assigned time frame. Importance of commitment by government sector, and simultaneous metrication throughout the economy.
CANADA	Steering Committee 5 (Construction Industry) (Metric Commission Canada) mid-1972 Sector Committee 5.1 (Construction-including design) First Meeting August 1973	1975	January 1, 1978 (1978 Designated as M-Year)	3 Years	End of 1980	6 Years	Program predominantly on schedule, with slippage in some provinces. Metric leadership by the government sector. M-Day twice deferred during planning stage.
UNITED STATES	Construction Industries Coordinating Committee (ANMC), January 1973 U.S. Metric Board, March 1978	Draft Program 1978	Draft Program January 1, 1985	4 Years from January 1, 1981	Not Specified	Not Specified	Draft Program developed in 1979. Consensus of industry needed for implementation.

none. Therefore, it challenges the industry's ability to cooperate which, in itself, has been difficult to accomplish in the past. By its very nature as a new, untried, one-off exercise, metrication engenders resistance by some, and concern by many. It is up to the industry, collectively, to assess and decide on the claims made both for and against the change.

This paper offers a model which might be used in the analysis leading up to a decision by the construction community on whether or not to commit itself to a voluntary conversion to metric measurement and, if so, on what type of program to develop and how to follow-through. The model in figure 8-2 shows five major steps in the decision process:

1. Study of Metric Issues and Concerns
2. Assessment of Benefits vs. Costs
3. Decision on Metric Conversion in Construction
4. Development of a Timetable for Conversion
5. Allocation of Responsibility for Program Implementation (National, Industry Sector or Group, Individual Organization).

Much of the work has already been done. The key stage is item three, the decision on metric conversion. There are no neutral options—in the event of a "yes," the timing becomes the next step and overriding issue; and the event of a "no," the industry will continue to adapt as it has done to date.

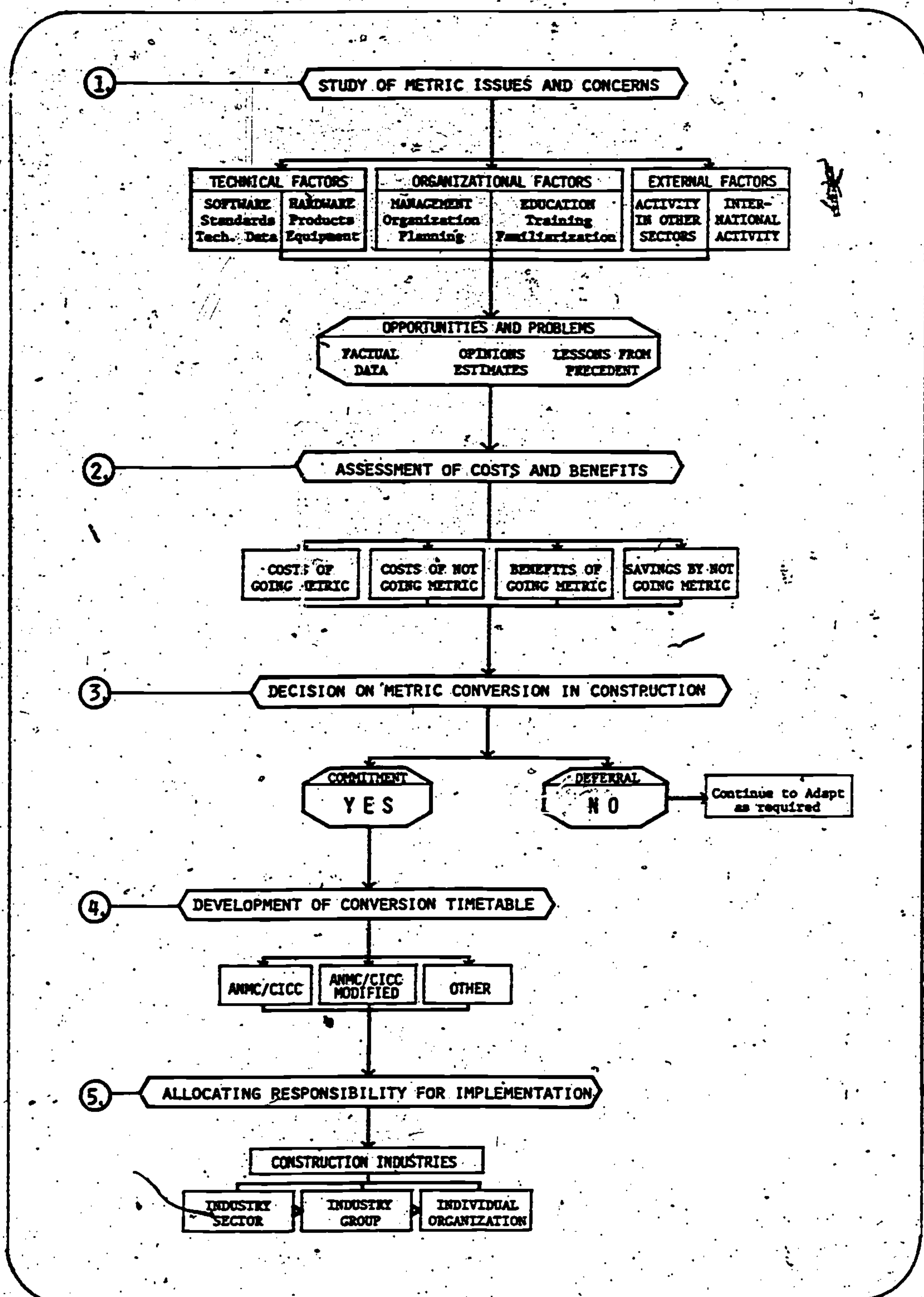
It must be noted that the "Timetable for Conversion" presented by the Construction Industries Coordinating Committee of the American National Metric Council was developed entirely by the private sector, based on consensus procedures and participation by representatives of nearly all major groups in the construction community. Any alternative would duplicate most of the work.

8.6 From Timetable to Implementation

If a time frame for metric conversion were to be endorsed by the construction industries, actual metric activities would occur in the practical world of design, production, and construction. Industry associations would have a major role to play by widely publicizing the timetable and its implications for their particular constituency, by assisting with implementation issues or problems, and by guiding members in reaching common responses during a transition. In addition to becoming information resources, the industry associations may also engage in metric training and/or familiarization activities.

Whereas metric "implementation" would occur at the task face—the local level—an overall advisory mechanism at the national level would be highly desirable to give guidance, provide for coordination between diverse sectors, resolve problems or conflicts, and, generally monitor progress or lack thereof. Ideally, the implementation phase should be coordinated by a group that is representative of all segments of the industry and respected by all segments. No compulsory powers would ever be required

Figure 8-2: A Model for Metrication Decisions in the U.S. Construction Industries



by such a group (or committee), since its very strength would lie in its advisory role. The alternative—not to have any overall guidance—would almost certainly prevent a cost-effective metric conversion in the construction industries.

At the sector level, supplementary committees would be needed to deal in more depth with specific implementation issues.

At the organizational level, planning for the change and its implementation will vary with size. In general, the larger the organization, the more opportunity exists to benefit from a conversion by using it to introduce variety reduction and rationalization of products, processes, and procedures; but, at the same time, the greater the chance of confusion if personnel is not properly briefed or trained. It is important that once a decision has been made to change to metric operations, a good metric climate and information flow be maintained both within and outside the organization.

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APPENDIX 1 - Extracts from NBS SP 345-12, U.S. Metric Study Interim Report, Testimony of Nationally Representative Groups

Page 4 of General Summary

THE CONSTRUCTION INDUSTRY

The construction industry is extremely complex and any conversion would require careful coordination in order to minimize problems. Most groups see little direct benefit to the industry from conversion. but many feel that it would present an ideal opportunity to advance the concept of modular construction and thus achieve important cost savings. A special problem for the industry would be the need to repair and remodel existing structures which would require added inventories to be maintained for many years.

Page 76 ff. - Details of Construction Industry Responses

VII. CONSTRUCTION

A SUMMARY OF INPUTS

The construction inputs were obtained with the special assistance of the Construction Affairs Committee of the Chamber of Commerce of the United States. Inputs were received from 26 construction related groups.

A majority of those groups (ten) expressing an opinion feel that metrication is inevitable and/or desirable. Only two groups are opposed to metrication; 14 either express no opinion or state the use of measurement systems does not affect their activities.

Almost all groups expressing an opinion on a preferred method of conversion indicate that any such program should be carried out only under a nationally-coordinated program. Some want a mandatory program and many suggest that a Federal agency take over responsibility for coordination. A 10-year transition time is commonly preferred, with the first 5 years used in converting codes, standards, and catalogs.

Cost and Benefits of Conversion

There is some resistance to change, usually based on estimates of transition costs with no foreseeable benefits. Many feel that conversion costs would be moderate, and once behind them the simplicity of metric usage would bring continuing savings, opportunities for more modular construction, and increased exports.

Transition costs would be less than for manufacturing industries since most equipment changes could be made by adjustments or by normal maintenance in 1 or 2 years. Some added costs would be anticipated during transition from the necessary accelerated revision of codes, standards, and design tables: added inventories causing some mix-ups at the job site: and some worker inefficiency while adjusting to metric sizes.

Training would not be a serious problem for the construction industry. The changeover would require new thinking, and "unlearning" of long-established relationships. Vocational and apprentice schools would have to change instruction to use metric units, but young workers entering the field with metric training would find measurements and calculations easier to make.

Some problems would be faced, during and after conversion, in repairing older structures built to customary standards. Dual inventories would have to be maintained on some materials for many years, and a variety of adapters would have to be stocked.

Modular Construction

More than half of the industry reports comment on the opportunity offered by metrication to advance the concept of modular construction and achieve important cost savings. Unified codes could reduce the number of sizes and simplify the fitting of components together on the job. Uniformity would reduce intermixing and on-site cutting, and save construction time. In addition, the use of metric modules would provide more opportunities for exchange of materials and test data abroad.

Metric standards for wallboard and plywood panels are only slightly smaller than our 4 by 8 foot standard. Producers could change over to metric sizes by merely adjusting machinery. Metric cement block dimensions are close to present U.S. sizes, with about a 3/8 inch difference in thickness. Since molds have a relatively short life, conversion of the machinery could take place during normal replacement. A major concern for all such building products manufacturers during any conversion process would be the need to continue to supply products made to inch standards at the same time as new metric-sized products are being produced.

Other Items

The conversion of land title descriptions to metric units is suggested only on a "go forward" basis, at the time property changes hands. No useful purpose would be served by converting existing records. Maps could be converted at the time of normal up-dating.

The experience of the construction industry in England, which is taking a leading role in metrication there, is cited by several trade associations as a good guide to the procedures which should be followed. All building construction in England will become metric by 1972, 7 years after the start of their metrication program.

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AIR-CONDITIONING AND REFRIGERATION INSTITUTE

The report is based on a survey of member firms. It indicates that there is little or no motivation or demand either for making the change to the metric system or for planning for possible metrication in the future.

Consideration of the replies results in a consensus of ACRI's General Standards Committee to the effect that while there appears to be no motivation for metrication at this time, the industry would cooperate in any nationally planned move for metrication, provided that a reasonable time period were provided—not less than 10 years.

AMERICAN CONCRETE INSTITUTE

When job mixing of concrete was replaced by ready-mixed concrete, the choice of units had little implication. But the current increase in precast construction is leading to two sets of standards, one in the United States and another abroad. Also, U.S. standards for reinforcing bars are not compatible with European practice.

To prepare the industry for eventual metrication, the American Concrete Institute now requires the use of metric units in all its publications, with customary units permitted. The new British building code includes a new metric standard for reinforcing bar sizes intended to be somewhat compatible with U.S. standards.

The concrete industry is presently going through a period of rapid change in practices and standards, and this would be an opportune time to convert to the metric system so that a separate conversion at a later date and at a greater cost, could be avoided.

AMERICAN INSTITUTE OF ARCHITECTS

The Board of Directors of the American Institute of Architects, in April 1970, passed the following resolution:

"Resolved, That the Board of Directors of the American Institute of Architects urges the completion of studies authorized by Public Law 90-472, particularly as these studies relate to the construction industry, and further urges that the metric system be adopted as the national standard of weights and measures in the United States of America."

Generally, architectural projects which are to be constructed in the United States are designed and constructed using the customary measurement system. Projects designed for construction out of the U.S. are usually designed using the system in general use at the location of their construction.

Any conversion should take place in a planned 10-year period because under that program the conversion would be more orderly, take less time, and allow the easier incorporation of a standardized dimensional framework into the product and dimensional standards of the United States.

AMERICAN INSTITUTE OF PLANNERS

With no planned program for metrication, the greatest problem would be comparability of data. For example, planners use data, such as miles, tons and gallons, from many Federal agencies. Changing to the metric system would require the use of conversion tables and careful descriptions of data. Without Federal Government coordination and widespread cooperation the conversion could be a tremendous undertaking. However, under a nationally coordinated program, planners would be affected no more than the general population.

AMERICAN LAND TITLE ASSOCIATION

The report of the American Land Title Association is based on a survey of association members. The survey basically indicates that while some of the members anticipate advantages, such as the efficiency and uniformity that might be realized if metrication could be accomplished, the consensus is that conversion of land title records is unnecessary since land is neither exported nor imported. Further, the consensus seems to be that such a change would be difficult, confusing, and expensive to the public as well as to title companies and would contribute to greater error in title evidencing and insuring.

The complexity of converting the huge number of public records now on file in numerous offices should be carefully considered if land title metrication were contemplated. Thought should be given to the possibility of converting land title records only on a go-forward basis if metrication comes; changing back-dated public record information to metric units in both public offices and title company files would mean very high cost with little apparent benefit.

In 1970, the ALTA Board of Governors adopted a resolution which reads in part as follows:

"Whereas, virtually all major industrial countries in this world have converted to the metric system: Now, therefore, be it resolved that the American Land Title Association sees no advantage in converting land titles to the metric system; nevertheless, the Association will cooperate in any decision made by the Congress to convert to the metric system."

AMERICAN PLYWOOD ASSOCIATION

The softwood plywood industry uses the customary system of weights and measures. At this time, it does not appear there is a significant possibility the industry would voluntarily changeover to the metric system unless all industry changed over at the direction of the Federal Government.

It appears the logical way to carry out a program of planned metrication in the plywood industry and in the United States would be to establish timetables for a fixed time period of perhaps 10 years, or more, with sufficient lead time established for coordination between related industries prior to work beginning on standards, construction modules, etc.

It seems important that industries be encouraged to stay as close to present sizes and modules as possible to minimize the impact of the change. In view of the popular 4 by 8 foot panel size and the capacity of existing equipment, a maximum new panel size equivalent to 49 by 98 inches would be feasible. Mere conversion to the metric language does not seem to offer too great a problem, but any radical changes in physical sizes could be chaotic because expensive equipment would become obsolete.

The greatest problem involved in metrication would probably be that of coordination between industries that are inter-related and that need to establish size standards that are compatible with each other.

AMERICAN ROAD BUILDERS' ASSOCIATION

The report is based upon a survey of selected member firms.

In general the survey indicates that there would be some advantages and some problems for the highway and airport construction industry in a national changeover to the metric system of measurement. In spite of the potential problems, the industry in general favors a changeover in the national interest of a more uniform and logical system of measurement.

Most members feel that a changeover is inevitable and desirable but that the change would require close coordination among different industries. This close coordination could only be affected by the Federal Government in a planned program of education, encouragement, and perhaps financial assistance.

Some segments of the highway industry could change rather quickly, others more slowly. The timing of a change must be coordinated to follow the logical sequence of operations beginning with planning and design and continuing through construction, testing, and maintenance. The change of engineering standards is often a time consuming process, and these changes must be coordinated with the industries involved.

AMERICAN SOCIETY OF CIVIL ENGINEERS

This report is based on the work of a special Metrication Committee of the American Society of Civil Engineers.

The Society has been on record since 1876 as favoring a conversion to the metric system. The many ASCE divisions have different opinions, but the majority seem to feel that conversion would present problems, but none that [illegible]e insurmountable, and, in fact, may lead to certain efficiencies.

THE ASSOCIATED GENERAL CONTRACTORS OF AMERICA THE NATIONAL CONSTRUCTORS ASSOCIATION

Based on experience reported by the British Metrication Board in 1970 relative to Great Britian's conversion to the metric system, and on the opinion of members of the associations, no increases in cost or difficulties due to conversion in the construction industry are foreseen, providing:

(1) That the conversion is orderly, planned and gradual in its effects; and

(2) That simultaneously with the conversion, the standards, codes and specifications which now prevail are modified to conform to the new units of measurement, and that nationally recognized bodies are urged to standardize the results of their efforts where possible and that local governmental bodies be encouraged to adopt model or regional codes.

BUILDING OFFICIALS AND CODE ADMINISTRATORS INTERNATIONAL

In this country, the customary system of measurement is used exclusively in building code enforcement. Since the customary system of measurement has served the necessary purposes satisfactorily and the construction and related industries use the customary system, the motives for instigating any change are based on matters not directly related to, but certainly concerning this industry.

The members of BOCA who have expressed an opinion on this subject favor a change to the metric system because:

A common system of measurement throughout the world would improve international trade and commerce and facilitate the exchange of materials, building techniques, and systems between nations.

A common system of measurement is imperative to share technological innovations between nations.

The metric system is convenient for engineering computations.

Building codes could be universally interpreted and adopted.

BOCA feels the possibility of complete metrication is negligible, unless a mandatory conversion process is adopted. Therefore, the members of the Building Officials and Code Administrators International strongly recommend that the Secretary of Commerce urge the Congress to take immediate action toward implementing a 20-year planned metrication program for the United States.

CALIFORNIA REDWOOD ASSOCIATION

The redwood industry would prefer a soft (i.e. language only) conversion to a hard (i.e. changes in size) one. Regardless of what occurs, however, it appears that there would be no insurmountable problems for the redwood industry due to metrication.

CONSULTING ENGINEERS COUNCIL

A major concern of the Consulting Engineers Council related to metrication is the increase in expenses that could be incurred in a transition period due to unfamiliarity with the metric system. This possible increase would need careful monitoring especially as to its effects on small engineering concerns, since a 5 percent cost increase could place severe burdens on such operations.

It is conceded that the metric system, as a more coherent system, would be more efficient. Also, engineers, with their specialized training, would be able to adapt more rapidly than others.

GYPSUM DRYWALL CONTRACTORS INTERNATIONAL

It is difficult to see beneficial results from metrication. Under planned metrication, problems resulting from new sizes could involve changes in building codes, building design, structural values, fire resistive requirements, sound transmission class ratings, architectural drawings and specifications, conversion of board production line speeds, drying kilns, possible changes in formulation, and many others. Until such time as architectural drawings and specifications, building codes, engineering standards, structural values, and other regulatory requirements are revised and reflected in metric units, the magnitude of any change to be encountered by the drywall industry in converting to the metric system would be difficult to ascertain.

ILLUMINATING ENGINEERING SOCIETY

Customary units of measure are used in the lighting industry, such as the ...c, footcandle, and footlambert. However, in all transactions of the Society, metric units are shown parenthetically following customary units. Metric units are used in the industry when related to export or foreign consulting.

Although most of the world now uses metric units, it still uses the foot as a module measure for many lighting products, such as fluorescent lamps. This may not change. If a planned program for metrication were to begin it would be a greater problem to educate the consumers and designers than to redesign parts or products.

INSTITUTE FOR MUNICIPAL ENGINEERING, AMERICAN PUBLIC WORKS ASSOCIATION

If the municipal engineer and public works official is to fulfill his role in protecting and enhancing the human environment, he must utilize the latest available technological innovations both at home and abroad. The adoption of the metric system by almost all nations of the world clearly establishes it as the universal system of measurement. The benefit of technical exchange on public works matters is greatly diminished by our failure to utilize and be conversant with this universal system.

Furthermore, municipal engineers and public works officials have expressed a general desire to change to the metric system. This is due primarily to its economy in performing engineering calculations and its increasing acceptance as a universal system of measurement. The use of the metric system for solving many engineering and public works problems requires one-tenth the time for calculation as compared to the customary system.

A planned metrication program would add approximately 5 percent to the cost of all public works operations during the conversion period. The technical benefits and long run economies of this effort, however, would greatly outweigh the conversion costs.

INTERNATIONAL ASSOCIATION OF WALL AND CEILING CONTRACTORS

An informal survey of the International Association of Wall and Ceiling Contractors' membership reveals that no members are opposed to a change to the metric system. If the change were done on a gradual basis—and as long as the entire construction industry changes—there should be no problems of major consequence in this segment of the industry.

INTERNATIONAL CONFERENCE OF BUILDING OFFICIALS

The use of the metric system in present activities is limited in a very minor way to the research program. Any changes in weights or measurement nomenclature in the enforcement field would be dictated by the needs of the material and construction industries. In other words, if the metric system is universally adopted in the production and design of lumber, steel, concrete, masonry and aluminum, model code groups would convert to the new system without difficulty. However, it is possible that adverse effects would result from evolutionary metrication not having the benefit of a coordinated program between Federal, state, and local governments and the construction industry.

It is likely that the majority of the members would initially resist conversion to the metric system since the field personnel are nontechnical. However, since the metric system is more efficient and more practical, the membership would eventually subscribe to the change following an adequate educational program by ICBO.

MOBILE HOME MANUFACTURERS ASSOCIATION

The Mobile Home Manufacturers Association as a group has no opinions or position to offer. Present unit usage is predominantly customary, but there seems to be little doubt that the industry would be able to accommodate any conversion without serious consequences.

NATIONAL ASSOCIATION OF HOME BUILDERS

This report is based upon a survey of a representative sample of the National Association of Home Builders' membership.

Converting to the metric system would create problems in the repair and remodeling of millions of homes and apartments already built in this country. These buildings, dimensioned in inches and feet, would need repairs long after completion of the conversion to the metric system. The intent of metrication should be to arrive at workable and easily understandable measurements.

Past experience in attempting to introduce modular coordination has shown that unless there is a coordinated effort, with some positive means of encouragement, an evolutionary process will probably be unsuccessful. Any system of planned metrication must take into consideration the fact that the construction industry is highly complex and over the years has developed highly efficient and economical methods for utilization of materials.

NATIONAL CONCRETE MASONRY ASSOCIATION

The concrete block industry almost exclusively utilizes the "modular coordination" concept, and the presently used module is based on the customary system. Conversion to a similar metric module would be possible but would cause two serious problems:

(1) Production equipment changes would be costly

(2) Modular customary blocks and modular metric blocks cannot be intermixed in the same job without destroying both the modular concept and the beauty of the wall.

Since concrete blocks are made and sold strictly on a local basis with no shipment in the international market, the concrete block industry sees no benefit resulting from metrication.

NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION

The report is based on a survey of member firms. The survey reveals that at present the customary system is primarily used, except that electrical units are metric. However, as more firms seek to go international, the need to "think metric" becomes more imperative. Increasing imports of materials is presently causing problems for domestic operators, including on-site personnel.

The overwhelming majority of the Association's members approve the idea of converting and express a sense of urgency that it be undertaken as soon as possible, following a carefully planned program.

The majority recommends the conversion be concurrent in architectural design and electrical materials manufacture and that the government take the lead in fostering and encouraging conversion on all fronts more or less concurrently.

NATIONAL FOREST PRODUCTS ASSOCIATION

It is unrealistic to think that the construction and building materials industries would permit a trend toward metrication, either voluntary or stimulated, to proceed without coordination. Such coordination should involve architectural planning, modular coordination and engineering design as well as product development and use.

The attitudes encountered most frequently in the forest products industry on the subject of metrication seem to be: (1) that the trend is an unavoidable one; (2) that its benefits to most segments of the industry have not been fully explained or understood; and (3) that the total cost over the period of conversion may be difficult to justify in terms of direct benefits. Reaction ranges from enthusiasm through cautious optimism to concern for cost and disruption of production and marketing practices.

It is generally believed that simple conversion of present measurement units to the metric system at the product level could be accomplished with minimal adjustment of equipment and training of production personnel. Volumetric determinations of log yield and conversion of land measurements to the metric system, however, are thought to be significant constraints where a dual system may be required for some time.

With respect to lumber use in building construction, the extent to which benefits of metric conversion could be translated into simplification of the building process and demonstrable construction economies would be a major factor in determining the pace of metrication and degree to which coordination of the effort would be encouraged and supported.

SHEET METAL AND AIR CONDITIONING CONTRACTORS' NATIONAL ASSOCIATION, INC.

If metrication is undertaken a planned program must be employed with a time table that would enable the contractors to initiate educational programming for their work forces. The major problem in the industry would be training journeymen and apprentices who are presently doing layout work on sheet materials to form three-dimensional products. This is the only trade in the construction industry that still fabricates that which it installs and this requires the use of an extensive shop facility for fabrication purposes.

Perhaps the item of greatest concern, however, would be the administrative ceiling on overhead allowed on government construction projects. Such restrictions should be increased to allow for added costs due to inefficiencies during conversion.

STRUCTURAL CLAY PRODUCTS INSTITUTE

The report is based on a questionnaire survey of members.

The attitude of the brick industry in the United States toward metrication can be described, at best, as "lukewarm." While it accepts the fact that the metric system is, basically, a more logical and simpler system of measurement than the one we have been using for centuries, it cannot see any economic benefits that would result from converting. It does see, however, a certain amount of confusion and expense during a transition period.

On the other hand, it is also cognizant of the fact that the United States will no doubt not let itself become an isolated nonmetric island in a metric world. Therefore, if the increased use of the metric system is inevitable in the U.S., the brick industry urges that it be accomplished under a nationally coordinated and planned program with a fixed time period of sufficient duration to permit everyone involved to accomplish metrication with a minimum of confusion and cost.

It would be hoped that a planned program could result in an industry agreement on a fewer number of what would be considered standard metric brick sizes. It could also result in agreement on some new and more optimum sizes, necessitating some retooling in the industry, with its attendant expense.

AN OVERVIEW OF THE CONSTRUCTION INDUSTRY'S UNIONS

The structure of the construction industry does not readily lend itself to major change. The industry is highly interrelated and both fragmented and decentralized with thousands of companies participating to some extent.

New construction should not be emphasized to the exclusion of renovation, remodeling, and repairing. These would each have an entirely different impact as far as metrication is concerned. If we convert to the metric system completely in the next 10 years, it would be easier to construct new buildings and nonbuildings than to repair the ones now in existence. Many of the buildings now standing will be in existence for the next one hundred years. Constructed and planned on a scale of inches and feet, they would present serious renovation and repair problems.

Another major consideration in the construction industry is its workforce. It consists of a large pool of people possessing varying degrees of necessary skills. There is constant movement in and out of this work force, and generally speaking, there is very weak industry attachment. It takes about 1.8 persons to fill one annual job.

Concerning metrication, in construction there is little or no present application and no past experience with the metric system. Existing exports of materials are insignificant now and probably will continue to be in the future. The reasons for that include the weight, bulk, and high cost of transportation.

Accommodation, or even adaption, would be better than conversion for the construction industry. The increased cost and very limited benefits that this industry would receive precludes efficient conversion. Metrication itself should not affect overall construction activity because this activity is limited to the cost and availability of long term capital. The priorities of what type of construction will be built are determined through the flow of this capital. Housing construction could be postponed to give priority to the conversion of plants, capital investments, and plant equipment.

Another factor which would affect the overall construction activity is the quality of the work force. Training would be needed to shift from the customary system to the metric system. Training is probably the most important element in the industry. The capacity of existing apprentice training systems, teaching aids, textbooks, and conversion materials would need to be analyzed; whom to train and how to train him would have to be decided. Recruitment would have to vary with age and geographic distribution. If, for example, a worker lives in a rural area and has to travel to training areas and classrooms, the time spent could be considerable. He should be compensated for time and transportation, creating an additional expense.

Additional concerns include the impact on the earnings of journeymen. There would be a strong possibility of lost income due to delays in scheduling. Also, many persons who are either unwilling or unable to learn, could be forced out of work.

[I]NTERNATIONAL BROTHERHOOD OF [E]LECTRICAL WORKERS

The International Brotherhood of Electrical Workers has no past experience with the metric system except the use of present electrical units which are metric. The cost of replacing required tools due to metrication would be small. However, a distinction should be made between the tools required by agreements, and tools craftsmen and journeymen carry as a personal convenience to expedite their work. Although the number of tools required by agreement is minimal, the craftsmen actually carry a significant number of additional tools. Reimbursement would probably be limited to required tools. The worker, unfortunately, would have to fund himself the replacement of those other tools. Training is estimated at 30 to 40 hours for journeymen and 50 to 80 hours for instructors at an undetermined expense. Conversion at this time would definitely not be advantageous.

[U]NITED BROTHERHOOD OF CARPENTERS AND [J]OINERS OF AMERICA

It is the opinion of this union that with the increase of worldwide trade a uniform measuring system is essential. The members have little, if any, contact with the metric system; therefore, the measuring tools and precision equipment used by the members would be a major problem if the metric system were adopted. Both construction and industrial workers are members in the union, and the replacement value of their tools would vary depending upon the segment of the trade in which they are employed.

An in-service training program of 40 hours for the coordinators and instructors of apprenticeship and journeymen classes would be required. An estimated 20-hour supplemental upgrading program would be needed in order to acquaint members with the metric system.

[O]PERATIVE PLASTERERS' AND CEMENT [M]ASONS' INTERNATIONAL ASSOCIATION [O]F THE UNITED STATES AND CANADA

The metric system is not used by the workmen in this industry simply because the advantages are not clear and the unfamiliarity with the system by the membership naturally adds up to an opposing viewpoint.

Conversion to the metric system would be calamitous to the membership, due mainly to the high number of elder members. In the event the use of the metric system is adopted, some kinds of total and absolute compensatory damages must be strongly considered for those who fail to grasp and master the techniques of the new system, thereby reducing or totally losing their earning power. Replacement of tools would be negligible in comparison with the tools and equipment of those in other crafts.

INTERNATIONAL BROTHERHOOD OF PAINTERS AND ALLIED TRADES

The experience of the members with the use of measures is primarily limited to linear and liquid or volume measuring, and most of the membership has been using the English system of measure in their day-to-day work experiences.

No members of the union have any past experience with conversion to the metric system; most members are probably not even familiar with it. Furthermore, there are no readily apparent advantages of conversion from the standpoint of the individual members of the union.

The impact of conversion on members in the building trades, primarily painters, glaziers, and floor coverers, relates mainly to tool replacement. They typically supply many of their own tools. Among the industrial workers, most of the paint makers use employer-supplied equipment. However, the maintenance painters supply many of their own tool kits, and besides painting, they are expected to perform other maintenance functions which may involve the use of micrometers and depth gages. Retraining in both areas would also be a concern. The amount of retraining would necessarily vary according to tradesmen's or industrial workers' present use of the customary system.

BRICKLAYERS, MASONS AND PLASTERERS INTERNATIONAL UNION OF AMERICA

If the metric system were adopted, there would be much resistance to the change at the outset. However, the tradesmen of this union could adapt to change with fewer problems than other trades. Successful conversion would require coordination of changes between material suppliers, architect designing engineers, and general and masonry contractors through joint meetings and efforts.

Advantages of metric usage may include its ultimate simplicity in calculation. Also, there may be some simplification of processes and construction if the system of measure were unified through the metric system. Greater economies through speed of construction could result if coordinated building design, building materials, and assembly techniques were brought about by a standardized measuring system.

The major disadvantage of metric usage would be costs and delays due to reeducation. A complete reeducation program of all workers would be necessary. There may be a total rejection by some of the older workmen at the outset. There would be some difficulty in job planning and estimating. Worker tool changes would also be required. These include a regular folding rule, 50 feet and 100 feet steel measuring tapes, and a framing square. The costs of such changes would be minimal.

CONSTRUCTION INDUSTRY CONFERENCE

Sponsored by the
U.S. Department of Commerce, National Bureau of Standards,
Gaithersburg, Maryland, October 5-6, 1970

Monday, October 5

9:30–10:15 *Opening Session:* Chairman Daniel V. DeSimone, Director, U.S. Metric Study

Welcome—"The National Bureau of Standards and Its Responsibilities Under the Metric Study Act"—Lawrence M. Kushner, Deputy Director, National Bureau of Standards

"The Construction Industry and the Metric System"—Douglas Whitlock; Whitlock, Markey & Tait; member, Metric System Study Advisory Panel

10:30–12:30 *Session One:* Building Design, Codes, and Standards

Participants: American Institute of Architects
Consulting Engineers Council of the U.S.A.
Building Officials Conference of America, Inc.
International Conference of Building Officials

1:30– 4:30 *Session Two:* Building Materials, Production and Sales

Participants: American Concrete Institute
National Concrete Masonry Association
Structural Clay Products Institute
National Forest Products Association
California Redwood Association
American Plywood Association

Tuesday, October 6

9:30–11:15 *Session Three:* General Contractors and Subcontractors

Participants: Associated General Contractors of America
National Constructors Association
Gypsum Drywall Contractors International
International Association of Wall and Ceiling Contractors

11:15–12:00 *Session Four:* Building Services

Participants: National Electrical Contractors Association, Inc.
Air Conditioning and Refrigeration Institute

1:00– 2:00 *Session Five:* Home Builders and Home Manufacturers

Participants: National Association of Home Builders
Mobile Home Manufacturers Association

2:15– 4:30 *Session Six:* Land Services and Heavy Construction

Participants: American Land Title Association
American Society of Civil Engineers
American Road Builders Association

APPENDIX 2 - Listing of Organizations Contacted for Information Included in Part 2 - "Current Activities in Professional and Industry Groups and State Government Policies, Metric Committees or Coordinators, Metric Actions."

Construction Related National Associations

Air Conditioning and Refrigeration Institute
Aluminum Association, The
American Association of Cost Engineers
American Concrete Institute
American Concrete Pipe Institute
American Congress on Surveying and Mapping
American Consulting Engineers Council
American Geophysical Union
American Hospital Association
American Institute of Architects
American Institute of Real Estate Appraisers
American Insurance Association
American Iron and Steel Institute
American Land Title Association
American National Standards Institute
American Plywood Association
American Society of Engineering Education
American Society for Testing and Materials
American Society of Building and Construction Inspectors
American Society of Civil Engineers
American Society of Heating, Refrigerating, and Air-Conditioning Engineers
American Society of Landscape Architects
American Society of Lighting Designers
American Society of Mechanical Engineers
American Society of Photogrammetry
American Society of Planning Officials
American Society of Plumbing Engineers
American Society of Safety Engineers, Inc.
American Society of Sanitary Engineering
Associated General Contractors of America
Association of Wall and Ceiling Industries, International
Brick Institute of America
Building Officials and Code Administrators International, Inc.
Business and Institutional Furniture Manufacturers Association
Carpenters and Joiners of America, United Brotherhood of
Cast Iron Soil Pipe Institute
Concrete Reinforcing Steel Institute
Construction Specifications Institute, The
Copper Development Association, The
Council of American Building Officials
Door and Hardware Institute

Gas Appliance Manufacturers Association
Gypsum Association
Hardwood Plywood Manufacturers Association
Illuminating Engineering Society
Institute of Business Designers
Institute of Real Estate Management
Interior Design Educators Council
International Association of Bridge, Structural, and Ornamental Iron Workers
International Association of Plumbing and Mechanical Officials
International Brotherhood of Electrical Workers
International Conference of Building Officials
International Masonry Institute
International Real Estate Federation, American Chapter
Laborers International Union of North America
Lead Industries Association
Manufactured Housing Institute
Mechanical Contractors Association
Metal Building Dealers Association
National Academy of Code Administration
National Asphalt Pavement Association
National Association of County Recorders and Clerks
National Association of Plumbing-Heating-Cooling Contractors
National Association of Home Builders
National Association of Home Manufacturers
National Association of Realtors
National Concrete Masonry Association
National Electrical Contractors Association
National Electrical Manufacturers Association
National Environmental Systems Contractors Association
National Fire Protection Association
National Forest Products Association
National Insulation Contractors Association, Inc.
National Lumber and Building Materials Dealer's Association
National Society of Professional Engineers
National Utility Contractors Association
Portland Cement Association
Prestressed Concrete Institute
Producer's Council, The
Realtors National Marketing Institute
Red Cedar Shingle and Handsplit Shake Bureau
Sheet Metal and Air-Conditioning Contractors National Association, Inc.
Society of American Registered Architects
Society of Industrial Realtors
Society of Plastics Industry
Society of Real Estate Appraisers
Southern Building Code Congress International, Inc.
Thermal Insulation Industrial Council
Tile Contractors Association of America, Inc.
Tile Council of America
Truss Plate Institute

Underwriters' Laboratories, Inc.
Women's Council of Realtors

Construction Related Individual Companies

American Standard/U.S. Plumbing Products
American Telegraph and Telephone
Armstrong Cork Company
T.R. Arnold and Associates, Inc.
Babcock and Wilcox
Bechtel Power Corporation
Bethlehem Steel Corporation
Bliss Steel Products
Boise-Cascade Housing Division
Braun and Wieder Construction Company
Buick Motor Division
Cahner's Publishing Company
Carrier International Corporation
Certain-Teed Products Corporation
Fleetwood Enterprises, Inc.
GAF Corporation
W.R. Grace and Company
Green Construction Company
Halstead and Mitchell
IBM Corporation
Johns-Manville World Headquarters
Koppers Company, Inc.
Lockhard Manufacturing Company
McGraw-Hill Information Systems
Mobil Research and Development Corporation
Monsanto Company, The
PPG Industries
Quaker-Maid, A Tappan Division
Smith, Hinchman and Grylls Associates
Structures Unlimited, Inc.
Tishman Research Corporation
Turner Construction Company
Union Carbide Corporation
U.S. Gypsum
Weyerhaeuser Company

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** (See instructions)	1. PUBLICATION OR REPORT NO. NBS SP 598	2. Performing Organ. Report No.	3. Publication Date October 1980

4. TITLE AND SUBTITLE

Metric Conversion in the Construction Industries - Technical Issues and Status

5. AUTHOR(S)

Hans J. Milton and Sandra A. Berry

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

Final

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Same as item 6.

10. SUPPLEMENTARY NOTES

Library of Congress Catalog Card Number: 80-600173

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

This Special Publication was prepared at the request of the Metric Symposium Planning Committee of the National Institute of Building Sciences (NIBS). It is intended to provide information on technical issues and status of metric conversion in the United States construction industries. It will be made available to attendees at the NIBS Symposium on "Metric Conversion in the Construction Community" to be held December 2-3, 1980, in Chicago, IL. In addition, it will be available to other affected parties in the construction community.

The report contains information on planning for the metric change, current metric activities of professional and industry groups, technical implications in the construction industries, dimensional coordination, metric building products and services, research issues, and timing. It is intended to provide assistance for informed decisionmaking relative to metric conversion for the U.S. construction industries. Also included in the report is a bibliography of relevant construction industries' metric technical information.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Construction industries; dimensional coordination; metric bibliography; metric conversion timetable; metric decision; metric product sizes; metric system (SI).

13. AVAILABILITY

☒ Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☒ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
☐ Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

144

15. Price

$5.50

USCOMM-DC 6043-P80

U.S. GOVERNMENT PRINTING OFFICE : 1980—331-394/6756

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