

CAM AND MANUFACTURED HOUSING

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A B S T R A C T

This CAM and Manufactured Housing report examines what present and near-future manufacturing technologies can be applied to the housing industry; the present state of housing technology in North America, Japan and Sweden; how the need to implement advanced technology can be identified and the benefits that can be derived; and an analysis approach to the implementation of advanced manufacturing concepts.

The major findings of the study are:

1. there is no significant example of CAD/CAM technology in the housing industry in North America;
2. the direct link between CAD and CAM does not exist in Sweden or Japan;
3. both Japan and Sweden have developed automated manufacturing technology which could be used as a reference point for a very progressive industry in Canada without the expense of the research and development carried out to date;
4. Canada has been left far behind the rest of the world in factory-built housing, but many opportunities exist for Canada to develop components for an automated housing factory which would be at the forefront of world housing technology;
5. the development of manufacturing technology is moving at a very rapid pace and any development of a housing factory should not only employ the latest technology, but must have the flexibility to adapt to continuing advances in technology. Ongoing research and development is a major component of maintaining an up-to-date manufacturing facility;
6. the economies of scale generally associated with the feasibility of automated manufacturing facilities for housing require far less production than anticipated. The panelized approach extends the market area of a factory due to the compactness of the units being moved; and
7. the consumer's perception of manufactured housing is a major roadblock to marketability, and yet manufactured housing can easily meet the quality and performance standards of on-site construction.

Canada is undoubtedly far behind countries like Sweden and Japan in the use of advanced technology in the manufactured housing industry. However, by applying what has been done in other countries to the North American marketplace and to the construction materials which are readily available in Canada, uniquely Canadian advanced technology housing systems can be developed which are at the forefront of housing technology and which would have significant market potential inside and outside of Canada.

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EXECUTIVE SUMMARY

The objective of this report initially was to study the link between the graphic information of CAD (Computer Aided Design) and the manufacturing component CAM (Computer Aided Manufacturing) within the context of the most current home manufacturing technology. Surprisingly, I found that the CAD/CAM housing factory is still in the development stage although there are presently factories in Japan and Sweden which use both CAD and CAM.

The United States, is very advanced in CAD/CAM and automated factories in the fields of automotives, microprocessor design and manufacturing, and aerospace, but a survey of panelized housing factories in the United States indicated that there was no significant example of CAD, CAM, or CAD/CAM technology being used, and the proposed trip to the U.S. to see factories would have been fruitless.

A trip was made to Anaheim, California to National Computer Graphics Association conference to review the latest in CAD/CAM technology, and the proposed trip to U.S. factories was changed to a trip to Japan to see their factories. Although their automated factories are among the most sophisticated in the world, the extensive use of steel and ceramics indicated that the technology is not directly transferable to Canada where wood is a much more acceptable construction medium for housing.

Sweden seemed to be the best example of automated house manufacturing technology and Lion Building Systems Inc. was contacted to get an overview of Swedish home manufacturing and to identify the practicality of importing the technology.

Nortech Micro Research Ltd. was hired as a consultant to outline the state-of-the-art concepts in manufacturing technology and to relate them to the housing industry, and to review the information gathered on the present state of home manufacturing technology.

The final report examines what present and near-future manufacturing technologies can be applied to the housing industry; the present state of housing technology in North America, Japan and Sweden; how the need to implement advanced technology can be identified and the benefits that can be derived; and an analysis approach to the implementation of advanced manufacturing concepts.

The major findings of the study are:

1. there is no significant example of CAD/CAM technology in the housing industry in North America;
2. the direct link between CAD and CAM does not exist in Sweden or Japan;
3. both Japan and Sweden have developed automated manufacturing technology which could be used as a reference point for a very progressive industry in Canada without the expense of the research and development carried out to date;
4. Canada has been left far behind the rest of the world in factory-built housing, but many opportunities exist for Canada to develop components for an automated housing factory which would be at the forefront of world housing technology;
5. the development of manufacturing technology is moving at a very rapid pace and any development of a housing factory should not only employ the latest technology, but must have the flexibility to adapt to continuing advances in technology. Ongoing research and development is a major component of maintaining an up-to-date manufacturing facility;

6. the economies of scale generally associated with the feasibility of automated manufacturing facilities for housing require far less production than anticipated. The panelized approach extends the market area of a factory due to the compactness of the units being moved; and
7. the consumer's perception of manufactured housing is a major roadblock to marketability, and yet manufactured housing can easily meet the quality and performance standards of on site construction.

1.0 INTRODUCTION

CAM (Computer Aided Manufacturing) is becoming a significant component in industry around the world in the fields of automotives, electronics, plastics, appliances and aerospace. The manufactured housing industry, particularly in North America, is very slow at adapting new technology and the present economic recession has stifled the prospects for much technological change to occur.

In Sweden and Japan, by contrast, very sophisticated automated factories have been developed which produce cost and design competitive, high quality housing in a fraction of the time of conventional construction. It appears that the automation of Canadian housing will be an adaptation of these systems. The introduction of a Swedish automated assembly line in Vancouver and overtures by Japanese factories to set up manufacturing facilities in the U.S. are indications that this is already taking place.

There is, however, much room for innovation in applying state of the art CAD/CAM (Computer Aided Design/Computer Aided Manufacturing) technology to current housing technology to meet the demand of the North American marketplace and to bring manufactured housing to the stage of advanced automated factories of other industrial sectors.

Lion Building Systems Inc. is bringing the best of Swedish house manufacturing technology to Canada to develop an automated housing factory. It is an adaptation of foreign technology to meet the demands of the Canadian marketplace and to integrate North American equipment and computer technology into the process to assure that the overall system functions efficiently in the Canadian environment.

Any decision to integrate advanced technology into an existing or proposed manufacturing facility is a complex process. It is initiated with an

understanding of the need to do so, and the benefits that can be derived. This must be followed by an indepth analysis of the need and what technologies can be employed to fulfill that need. Any decision to automate must be financially motivated and, therefore, requires a thorough understanding of the building approach, the market, and available technology.

This report will describe the state of the art in housing and manufacturing technology and suggests a general approach for integrating and implementing that technology.

The study begins with a description of the automated manufacturing facility which Lion Building Systems Inc. is presently building in Vancouver. As the only such facility in North America, it will not only help to introduce the technology to the reader, but is an indication of how the implementation of advanced home manufacturing technology is likely to evolve in Canada.

The range of automated factory technologies from Artificial Intelligence, which is still five years away from being fully integrated into manufacturing, to the most basic CAD (Computer Aided Design) systems are described. The degree to which the technology has reached the international housing industry is outlined with specific reference to the Japanese and Swedish manufactured housing industries.

Computers are then discussed in order to outline some of the significant considerations in choosing a computer within the context of CAD/CAM.

The report goes on to describe a process by which to recognize the need for CAD/CAM technology and some of the possible benefits, and a method of analysing a factory operation in order to decide the extent to which advanced technology should be employed.

2.0 CAM MANUFACTURING PROCESS

The following description of a CAM housing system for panelized housing components was provided by Lion Building Systems Inc. and used with their permission. It is an adaptation of a Swedish housing system for the North American market. It is used as an example of the state of the art in CAM manufactured housing because it is an example of existing technology which is applicable to the Canadian market.

2.1 The Product

The product is the Lion Building System (LB system) which, broken down to its smallest design component, is based on a 300 millimetre module. The components of the product, compared to those of an average house construction are:

<u>Components</u>	<u>LBS House</u>	<u>Average House</u>
- roof/ceiling panels	R-40/RSI-7	R-28/RSI-4.9
- wall panels	R-30/RSI-5.2	R-12/RSI-2.1
- floor panels	R-30/RSI-5.2	no standard
- windows	wood framed triple glazed	aluminium double glazed
- air tight	air to air heat exchanged	(house is not built air tight)
- R.C. Hydro Rating Energy Efficiency	Super Double 'E' Standard	Minimum Code

The flexibility of the product enables the basic design of a house to be translated into "panelized" components that can be arranged and assembled in accordance with the builder's or buyer's requirements. The standards set for LBS panel materials, assembly, content and quality exceed industry standards and requirements for walls, doors, windows, floors and ceilings. All panels have specified maximum dimensions so that they can be transported easily and safely in containers to the building site. The system of erecting and interlocking the panels involves a four man crew and a crane and, in most cases, can be completed within a day of arrival on-site. Electrical and plumbing would then be hooked up, interior painting would be done, and floor finishes installed.

The LB system can be used for single family houses, semi-detached units, row housing, cottages and condominiums up to 3 storeys high, as well as small office buildings and commercial structures.

Essentially, the degree of self-help in finishing the structure is the customer's option, but the LBS product can be fully packaged (with suppliers and finishing contractors) to provide a complete turn-key unit to the buyer.

The advantages of this system over conventional construction as outlined in LBS's system are:

- less expensive than other construction (due to fewer manhours and related expenses);
- more quality control of materials (all wood material is kiln dried);
- provides superior heat-energy efficiency and savings (due to insulation values for components and airtight construction);
- the computerized manufacturing process ensures a higher quality product; and
- construction time is reduced considerably.

2.2 The Manufacturing Process

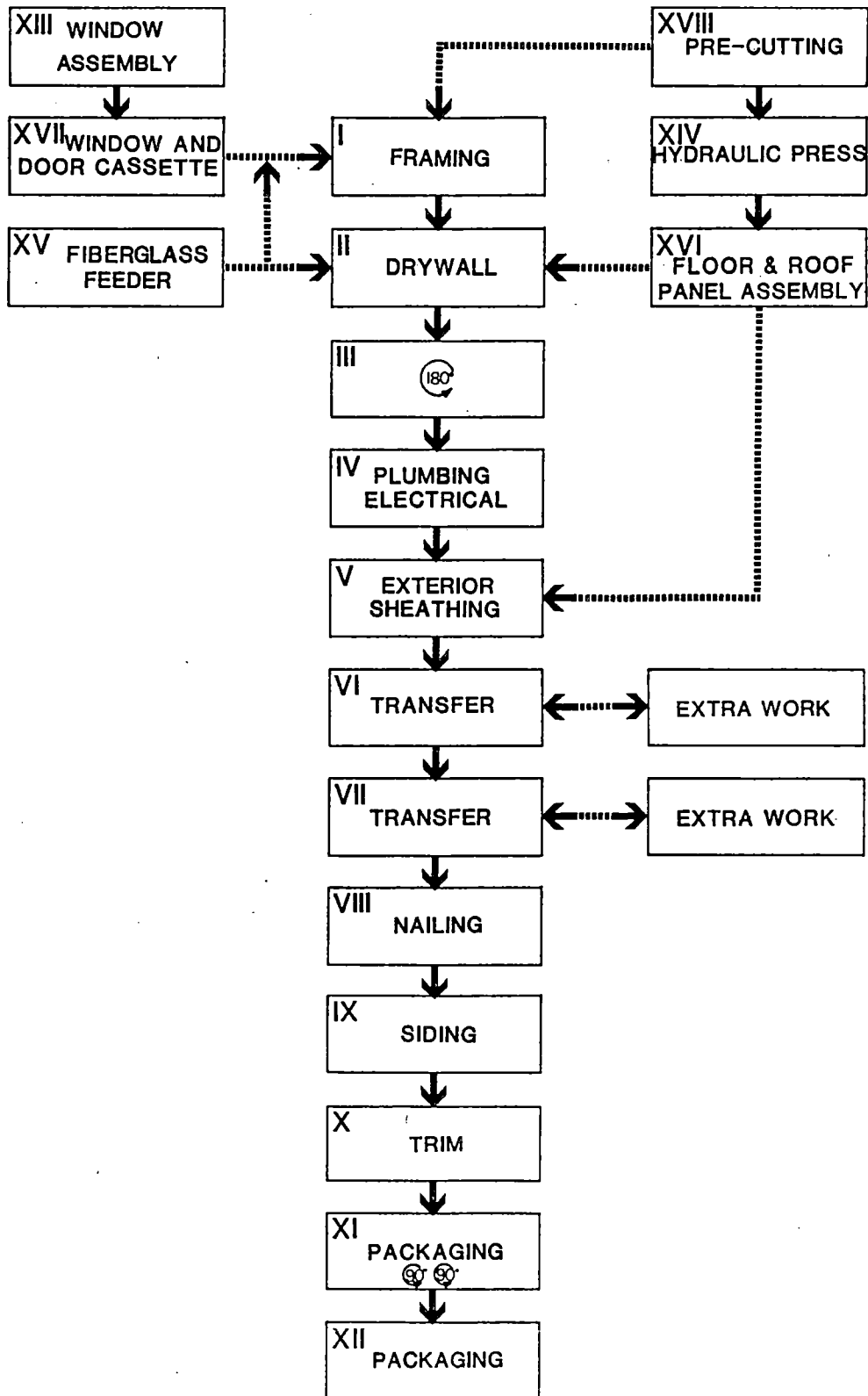
All work stations are totally integrated into one process which is preprogrammed from the design office in accordance with the specifications. While there is some manual work done at some of the workstations, all directions and materials are CAM input, based on the CAD program. Inherently, the requirement for labour is the semi-skilled rather than the skilled because of the intelligence of the machinery. The machinery functions for all the heavy lifts and movements and the work done by the operator is generally supervisory and is therefore not dependent on the strength of the worker. All machinery is designed and manufactured with ease of maintenance in mind. All work components, such as hydraulic pneumatic cylinders, nailing, screwing and stapling machines and basic moving parts, can easily be removed and replaced with spares without jeopardizing the production schedule. All fastening equipment is North American-made and has local representation for maintenance, and supply of nails, staples and screws. Following is a description of the manufacturing process. See Figure 1 for a factory schematic layout.

Station I - Framing Assembler

At this station the wall framing, including windows and doors, are assembled. The operator feeds the framing machine with pre-cut studs, sills, and top plates which are then assembled complete with the framed windows and door elements. The video display unit (VDU) indicates the structural elements to be fed in and the assembly method. The computer within the machine then directs the nailing, drilling, cutting and forward feeding of the framework. As the framework is fed forward, it passes under a bridge which dispenses the vapour barrier.

FIGURE 3

FACTORY SCHEMATIC



The station consists of the following equipment:

- 2 saws
- 2 pneumatic clamps for cutting and holding the sills and top plates
- 2 pneumatic presses (10 ton) for gangnailing when extending the sills and top plates
- 1 drill
- 4 Duo-Fast nailing guns
- 4 pneumatic clamps for holding sills and top plates and studs together
- 1 control panel with VDU
- 1 bridge for vapour barrier dispensing
- 1 towbridge for feeding the work piece forward

The computer has the following functions:

1. feeding the structural elements and forward feeding of assembled frame;
2. determining the wall length;
3. providing information on the sizing and location of doors and windows;
4. drilling the top plate for service conduits; and
5. marking the work for instructions at later workstations.

The computer can be operated remotely from the design office or directly at the workstation by the operator.

Station II - Drywall Application

At this station the drywall is applied by the operator who lays the pre-cut gypsum board onto the frame. This workstation trues the frame, and once the drywall is applied, it is passed under a screwing bridge which automatically screws the sheets in place. This station is equipped with conveyor belts for moving the frame, one bridge with 4 drills (each drill capable of drilling 4 different hole dimensions): 12 duo-fast nailing guns; and 1 bridge with 6 automatic screwdrivers.

Station III 3(a) and 3(b)

At this station the framework is flipped through 180° and directed to a specified assembly line. This station is equipped with 2 tables which lift the frame each through 90°. This station has conveyor belts to move the framework both longitudinally and laterally, and 5 pneumatic roller extenders on each table for lateral movement of the framework. The 2 tables share a 100 litre airtank operated by a 5.5 kilowatt pump providing a volume of 16 litres per minute. The tables, furthermore, are on rails which allows movement of the total station sideways.

Stations IV and VI - Workstations

At these stations, plumbing and electrical conduits are installed. Station VI is used as a side shunt when a wall section needs extra work. Station IV is mainly used as a transfer to Workstation V. This station, which consists of roller tables, is also hooked up to conveyor belts powered by a 2 kilowatt motor for forward feeding of the wall units.

Stations V and VIII - Workstations

Exterior sheeting materials are applied here. When high production is required, these tables also perform the same function as those in Workstations IV and VI. The equipment consists of conveyor belts, roller tables for forward and lateral movement of work pieces using 5 pneumatic roller extenders for sideway movement. Station V also contains a bridge with a dispenser for overlays.

Station VIII - Nailing Station

At this station the wall sections are trued and the sheeting materials are nailed. Should furrings be required on the work piece this station will allow automatic jigs to lay the furring and to complete the fastening. The equipment again consists of a roller table with conveyor belts for movement, powered by a 2 kilowatt motor. Jigs and clamps are pneumatically controlled for truing the frame and the bridge has 6 Duo-Fast nailing guns and 12 Duo-Fast staplers.

Station IX - Siding Application

At this station the wall is moved into place, adjusted automatically and clamped into position. The operator then manually lays siding materials onto the piece which will subsequently be passed under a nailing bridge which will automatically secure the siding to the piece. The equipment consists of a roller table with adjustable bridge (100 mm to 350 mm) with 12 Duo-Fast nailing guns and jigs for wood siding.

Station X - Trim Application

This manual workstation consists of a roller table where an operator with small tools will do trimming applications.

Station XI - Wall Component Packaging

The wall units are moved into this station, and tilted through 90°. The wall is then moved sideways to a stopping position and cassetted into package form ready for the outfeeding station. The equipment consists of roller table and pneumatic tilt.

Station XII - Packaging and Outfeed

At this station the upright wall sections are bound together by building unit and ready to be outfed. Equipment consists of a 2 x 25 meter roller table.

Station XIII - Window and Door Assembly Tables

Window and door elements are assembled with a primary frame before they are moved to be fitted in at Station I. These tables are pneumatically adjustable and will accommodate the different window and door sizes required. The table can also be tilted 90°. It has 1 nailing gun and pneumatic clamps for holding the frame and window/doors in place.

Station XIV - Hydraulic Press

This station is capable of manufacturing composite studs and floor joists. The equipment consists of jig tables to true on the frame (13 meters) with hydraulic press heads of 400 x 1 000 mm with a 10 ton capacity.

Station XV - Fibrebatt Feeder

Bulk mineral fibrebatt insulation is fed by conveyor into this machine which is preprogrammed to cut the fibreglas to the exact dimensions required by the work piece being constructed. Using a series of 5 conveyor belts, stoppers and a moving saw with a 500 mm diameter blade, the machine (with information from Workstation I), automatically feeds insulation material into the framework. This station is also capable of reading directions, imprinted on the framework from Station I, with the use of a small laser reader. The machine in its entirety is fed into Workstation I from the side.

Station XVI - Floor and Roof Panel Assembler

Attached to Station II, this station, consisting of 2 roller tables and a scissor feeder for the structural elements, automatically places floor joists into pneumatically operated jigs to the pre-programmed design and clamps these into place and conducts automatic nailing. It then moves the work piece to Station II for integration into the main assembly line. This station consists of 2 tables each with 4 automatic nailers and 2 small duo-nailers for hand operation.

Station XVII - Window and Door Cassette Feeder

This station consists of an overhead conveyor system which feeds cassettes of doors and windows, and lifts them automatically from a scissor stack into the work position. This is fed into Workstation I.

Station XVIII - Pre-cutter

The pre-cutter consists of automatic feeders with an electronically operated cross-cut saw capable of cutting angles in 3 planes. At this station all structural members required in the manufacturing process are fed in to be pre-cut in accordance with the program.

The finished house from this process will require 40 manhours to assemble on a serviced foundation. Over and above that, 250 manhours will be required for plumbing and electrical.

This method of construction is somewhat different than that used in North America where panelized construction tends to include the production of a wet core module which contains the plumbing, heating, and electrical modules ready to be hooked up to on-site services. In this case the plumbing wall is roughed in and left open so that it can be worked on on site.

There is no question that the housing system described above far exceeds the housing technology in Canada, but it is important to keep in mind, when importing such advanced technology, that it must be adapted to the Canadian market. Such considerations as availability of materials, codes and approval processes, design marketability, energy systems, and transportation to markets must all be reviewed.

3.0 PRESENT STATE-OF-THE-ART IN THE INTEGRATION OF COMPUTERS AND MANUFACTURING

As computer technology and computer controlled machines become more a part of the industrial environment, and as the technology continues to develop at a very rapid pace, manufacturing concepts are changing. The "thinking" factory, run on computer intelligence, is only a few years away. Although the housing industry is rather slow to embrace technological innovation, pure economics will assure that it, too, will move towards the fully automated factory in the near future.

The capability exists today to design a house on a computer, to view the house in three dimensions in perspective from any angle, to change colours through a pallet of thousands of different colours, shade the model to represent the sun angle for any time of day or year, and, from that graphic information, generate numerical control data which will run the equipment in an automated factory to produce that house in a matter of hours.

Following is a description of present and future technology which is changing, and will change, the factory of the future.

3.1 AI (Artificial Intelligence)

Artificial Intelligence (AI) is concerned with designing computer systems that exhibit the characteristics associated with intelligence in human behaviour. AI is the discipline of computer science dedicated to the concept that computers can be made intelligent, rather than to simulate intelligence. In recent years, artificial intelligence has been applied to a variety of areas including medicine, chemistry, machine vision, education, and geology. The success of AI has led to a widespread interest in understanding and applying its concepts to a multitude of problem domains.

To understand artificial intelligence one must understand the basic ideas for organizing knowledge, exploiting constraints, searching spaces, controlling attention, and learning.

The implementation of AI in automated factories is still five years away, but it will be a very significant factor in the factory of the future (Introduction to Artificial Intelligence, John F. Gilmore, Georgia Institute of Technology). AI, in its present form, involves "cloning experts" who are analyzing large amounts of data and making critical decisions. An example is the analysis of seismic information for resource exploration.

3.2 CIM (Computer Integrated Manufacturing)

CIM is a concept of a totally automated factory in which all manufacturing information and materials are integrated and controlled by a CAD/CAM system. CIM enables production planners, schedulers, shop floor foremen, and accountants to use the same data base as product designers and engineers.

CIM represents the true automation of a factory process, and is a concept which should be a goal to be worked towards in manufacturing. CIM is not available as a commercial package today, but the industry sectors which have CIM have generally customized the technology for their own use. This is understandable, since very few production concepts will ever be the same. An example of CIM is the 'ghost factory' used to produce plastic pop bottles. The factory operates 24 hours a day without manpower, in a unlighted and unheated building.

3.3 CAD/CAM (Computer Aided Design/Computer Aided Manufacturing)

The term CAD/CAM refers to the integration of computers into the production process to improve productivity. Through interaction with a design terminal or work station, the designer creates a product design in detail and once satisfied, can command the system to make a hard copy or to generate a computer tape to guide computer - controlled machine tools on the factory floor. As a design is developed, the computer graphics system accumulates and stores physically related data. The precise location, dimensions, descriptive text and other priorities of every design element that helps to define the component are identified.

Due to the great variety of components in a single house and the need to constantly vary these components to suit design changes, CAD/CAM is a more realistic goal for manufactured housing than CIM.

3.4 CAM

Unlike CAD/CAM, CAM is not necessarily all encompassing within a factory process. CAM is a process which employs computer technology to manage and

control the operations of a manufacturing facility. It can be applied to a small part of a factory's operating process, sometimes referred to as a production 'cell'. This allows a factory to build 'cells' or 'centres of technology' over a period of time as the processes warrant.

3.4.1 CAM Concepts

Today CAM exists in many forms as listed below:

1. FMS: Flexible Manufacturing Systems and cells.
FMS is a group of automatic tools, such as CNC machine tools, that can randomly process a group of parts having different process sequences and process cycles. The system can adapt automatically to changes of part production mixes and levels of output.
2. CNC: Computerized Numerical Control programming is used for operational processing, including robotic programming and operation. It is a technique whereby a machine tool control uses a computer to store NC instructions generated earlier by a CAD/CAM system.
3. DNC: Direct Numerical Control. A system in which sets of NC machine instructions are connected to a computer to establish a direct interrelationship between the DNC command and the machine tool.
4. AMH: 'Automated Material Handling' Systems. AMH is a computerized movement system for manufactured components.
5. MRP : 'Manufacturing resource planning.' MRP covers complete inventory, labor and resource planning control.

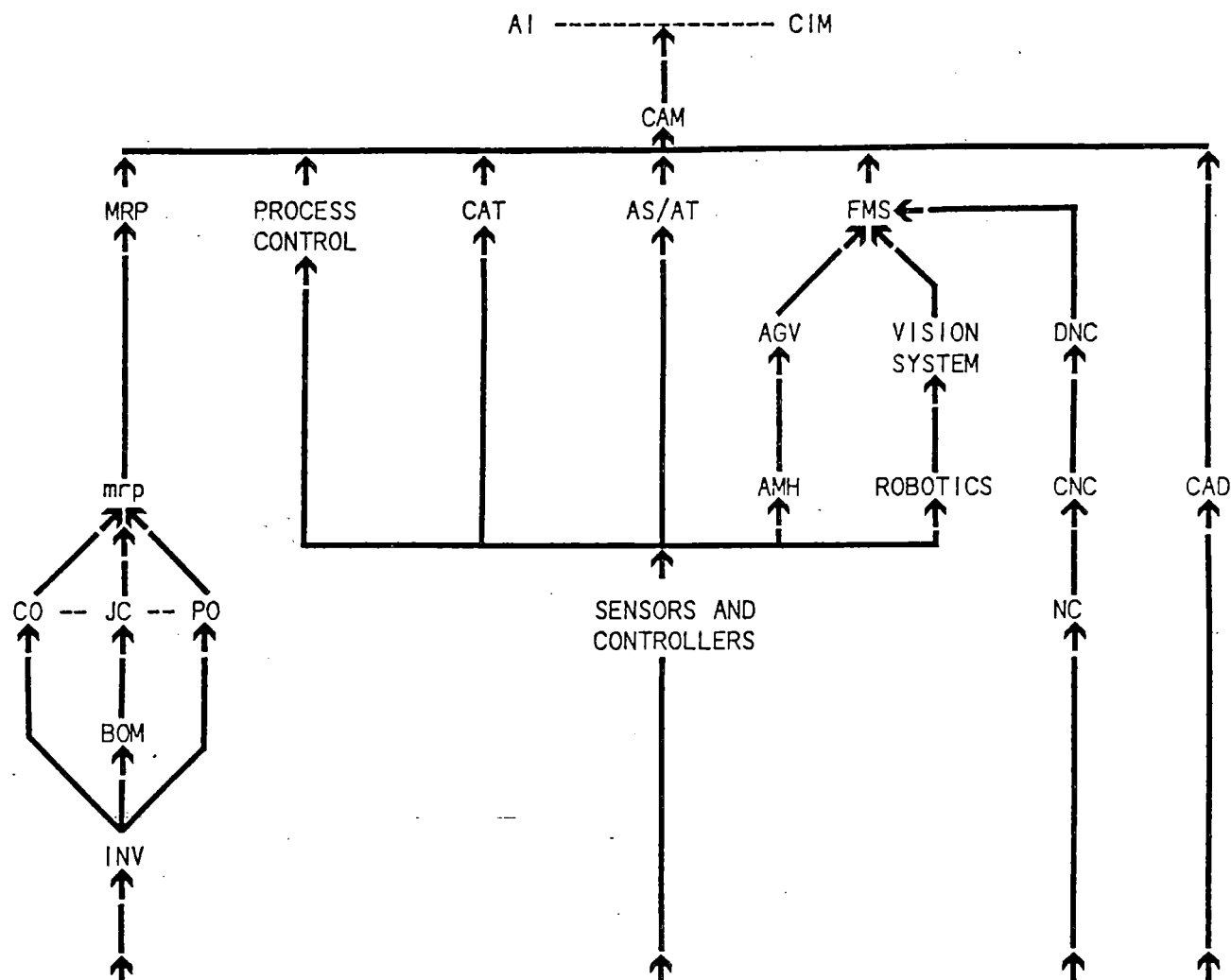
The progression of technology in a factory concept is very complex and can be generalized as shown in Figure 2.

3.4.2 CAM Implementation

A general order of progression and priority suitable for most companies to follow, is outlined below:

1. MRP. A 'material and resource handling system' which allows a company to work towards a zero inventory level or a 'just-in-time' operational process.
2. Islands of technology. Individual areas of an operation have mechanization, automation or both applied to the operational process. These are often referred to as 'cells' or work stations. Their purposes are as sites for dull, dirty or dangerous jobs, quality improvements, preventing bottlenecks and reducing labour costs.
3. AMH. Automated material handling systems allow a factory to mechanize, automate, or both, the moving of materials for the reduction of labour. This may be because of heavy weights of the materials being used, long distances the materials must be moved, or simply to handle a boring and repetitive job process.
4. CAD. Computer aided design allows a factory to eliminate the up-front time for a project prior to the initiation of the manufacturing process. It also allows the factory to carry out custom jobs by altering existing work and turning out complete plans and material lists fast and efficiently.
5. ASSEMBLY. For repetitive operations, the mechanization or automation of the assembly process is essential. This is usually in a high labour area where significant labour and quality improvements can be realized.

FIGURE 2: PROGRESSION OF TECHNOLOGY



- AGV: Automated Guided Vehicles
- AI: Artificial Intelligence
- AMH: Automated Material Handling
- AS/AR: Automatic storage/automatic retrieval
- BOM: Bill of Materials
- CAD: Computed Aided Design
- CAM: Computer Aided Manufacturing
- CAT: Computer automated testing
- CIM: Computer Integrated Manufacturing
- CNC: Computerized Numerical Control
- CO: Customer Orders
- DNC: Direct Numerical Control
- FMS: Flexible Manufacturing System
- INV: Inventory
- JC: Job Costing
- MRP: Manufacturing Resource Planning
- mrp: Material Requirements Planning
- NC: Numerical Control
- PO: Purchase Orders

3.5 CAD (Computer Aided Design and Drafting)

While numerically controlled machines can be programmed and operated independently of CAD technology, CAD is a significant component of the major factory operations in Japan and Sweden. None of the factories studied has a direct CAD-CAM link; however, it is being vigorously pursued; computer technology has advanced to the point where implementation would not be difficult.

The following is a description of CAD tools and how they are used.

3.5.1 The Use of Computer Aided Design Technology

The primary functional purpose of a computer aided design and drafting system is to assist the user in creating design and technical drawings. This is done by taking advantage of the repetitive nature of such drawings, creating a "library," or "computerized template" of standard graphic symbols that are used over and over again. These library symbols are created on the CAD system only once, and are then stored on disk (and/or tape) for use in specific drawings. The symbols may be "primitives" such as lines, arcs, circles, or standard symbols such as doors, stairs, plumbing fixtures, electrical symbols, or user defined macros, i.e., user created symbols derived from primitives and stored as a single entity.

By securing a "menu" of symbols to the sensitized work surface (data tablet or digitizing tablet), the user may pick and select the symbol to be used with the electronic pen. Various graphic system commands are used in conjunction with the library of symbols to add, delete, connect, rotate or move these components interactively. The commands may be entered into the system via an electronic pen, alphanumeric keyboard, function keyboard or menu (see menu Figure 3).

INTERGRAPH

TEXT

TX- Text Size
TH- Text Height
TW- Text Width
FT- Font
SN- Active Symbol Font
NN- Node Number
LL- Line Length
LS- Line Spacing
TI- Tag Increment

PRECISION INPUT

XY- Coordinates (Drawing)
DI- Distance & Direction (View)
DL- Delta XY, Z (Drawing)
DX- Delta XY, Z (View)
AX- Auxiliary Coordinates (Absolute)
AD- Delta Auxiliary Coordinates

STREAM DIGITIZE

SD- Delta Distance
ST- Tolerance

CELLS

AC- Active Cell
CM- Cell Matrix
CC- Create Cell
CD- Delete Cell
CR- Rename Cell

ATTRIBUTES

AE- Active Entity
CS- Change Attribute Spec
RA- Review Attributes
DS- Define Search Spec
OW- Define Owner
DR- Display Report
FU- Full Universe File
DA- Displayable Attr Type
RS- Report Specification
RO- Report Output File

COLOR

CT- Color Table
CO- Color Name/Value

FILES

RD- Retrieve Design
RR- Reference File (1,2,3)
RC- Retrieve Cell Library
NC- New Cell Library
OX- Retrieve UC Index
NX- New UC Index
DB- Retrieve DMRS Data Base
EL- Generate Element List
AL- Active Element List
FF- File Fence
SF- Separate Fence
XD- Exchange Design (1,2,3)

SCALE

AS- XY, Z Scale
XS- X Axis Scale
YS- Y Axis Scale
ZS- Z Axis Scale

TERMINATOR

LT- Terminator Name
TS- Terminator Scale

VIEWS

WO- Window Origin
AZ- Set Active Depth
DZ- Change Active Depth
DP- Set Display Depths
DD- Change Display Depths
VH- Select Named View
RV- Rotate View

PATTERNS

AP- Active Pattern Cell
PA- Active Pattern Angle
PS- Active Pattern Scale
PD- Active Pattern Delta

LEVELS

LV- Active Level
ON- Level On
OF- Level Off
DL- Display Level (Ref. File)
BL- Level Off (Ref. File)

WISC

AT- Activate Tutorial
TV- Dimension Tolerance
LD- Dimension Level
AA- Active Angle
GU- Units Per Grid
GR- Reference Grid
UR- Unit Roundoff
GD- Global Origin
LC- Active Line Style
WT- Active Line Weight
CL- Class Mask
AP- Select Active Menu
UC- Select User Command
PT- Active Point
DF- Down Load Font

POLYGONS SELECT			PLOTS REQUEST			DIGITIZER SETUP			ANGULAR DIMENSIONING UNITS POINT ARC LENGTH DIAMETER			DIMENSIONING CONTROL PLACEMENT WIDNESS LINES JUSTIFICATION AUTO MAN ON OFF L C R			ACTIVE ENTITY RENAME WITH ATTACH ON/OFF			REVIEW SCALE ELEMENT REPORT			SET OWNERSHIP SINGLE ELEMENT FENCE CONTENTS			SCALE AS=1 1"=1'		
MEASURE X,Y,Z DISTANCE IN LINE ELEMENT ANGLE BETWEEN LINES PERPENDICULAR TO LINE ARC DISTANCE CUM MIN AUX COORD AUX DELTA			RADIAL DIMENSIONING RADIUS DIAMETER			LINEAR DIMENSIONING ACTIVE AXIS SIZE LOCATION LABEL LINE			ACTIVE OWNER CHANGE PARENT CHILD CLEAR			DISPLAYABLE ATTR ATTACH SINGLE FENCE SEQUENCE			ANGLE 1 90 180 270											
PATTERNS LINEAR SCALE AREA REVIEW ATTR SEGMENT MULTI SINGLE DELAY ON/OFF			USER COMMANDS 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20			ATTRIBUTE MANIPULATION ATTACH ACTIVE ENTITY CHANGE ATTR VALUES REMOVE ATTRIBUTES DELETE ENTITY ON/OFF COPY ATTRIBUTES			COMPRESS DESIGN			DESIGN OPTIONS			FILE DESIGN			DISPLAY IN EXHIBIT								
LOCKS TEXT AXIS UNIT SNAP OFF KEY/PT PROJ REF FILE SNAP 1 2 3 GRID ANGLE SCALE GRAPHIC GROUP LEVEL INF LINES BORE LOCATE ATTN INSIDE OVERLAP CLIP			RASTER VIEW CONTROL ZOOM IN OUT PAN EXIT EXIT & SAVE DRAG ON/OFF DYNAMIC AREA DROP VOLUME			AUX COORDINATE SYS VIEW ALIGN MOVE			UPDATE L R BOTH VIEW STOP DRAWING																	
FAST DISPLAY ON/OFF CURVE ARC (L) LIPSE TEXT FONT CELL			DISPLAY ON/OFF WEIGHT PATTERN TEXT ENTER DATA FIELD LEVEL SYMBOL DIMEN DATA CONST LINES GRID DELAY L R VIEW ON VIEW OFF COPY SWAP OVER VIEW ON/OFF TUTOR VIEW ALIGN VIEW ZOOM IN OUT FIT WINDOW AREA CENTER VOLUME			VIEW SCALE VIEW ROTATION DEPTH ACTIVE DISPLAY			VIEW CONTROL VIEW SCALE VIEW ROTATION DEPTH			VIEW SCALE VIEW ROTATION DEPTH			VIEW ROTATION DEPTH			DEPTH ACTIVE DISPLAY								
FENCE CONTENTS MANIPULATIONS MOVE ROTATE ORIG COPY COPY SCALE ORIG COPY DELETE MIRROR ORIG V H L CHANGE SYMBOL MIRROR COPY V H L ADD TO WORKING SET ORIGINAL COPY			FENCE ARC PARTIAL ELLIPSE FILLET PARAB SPIRAL ELLIPSE CIRCLE LINE LINE STRING SHAPE CURVE CELL TEXT POINT MODIFY RADIUS MODIFY ANGLE AXIS MOVE			ELEMENT MANIPULATIONS COPY SCALE DELETE CHANGE SYMBOL PARTIAL DELETE SQUARE PROJECT SURFACE OF REV MOVE ROTATE ORIG COPY MODIFY DROP CLEAR INTER MIRROR ORIG V H L MIRROR COPY V H L			WORKING SET DROP ADD TO WORKING SET ORIGINAL COPY			CREATE CHAIN DROP ADD TO WORKING SET ORIGINAL COPY			TEXT ATTRIBUTES DISPLAY CHANGE			COPY & INCREMENT TEXT ENTER DATA			TEXT JUSTIFICATION "XX" "XX" "XX" "XX" "XX" "XX" "XX" "XX" "XX"					
ADJUST TRAVERSE COPY PARALLEL EXTEND LINE CONSTRUCT LINE CONSTRUCT LINE AT AA CONSTRUCT BISECTOR CONSTRUCT TANGENT CIRCLE CONST TAN ARC CONSTRUCT LINE BETWEEN ELEM CONSTRUCT POINT			ENTER DATA FILL IN SING AUTO COPY JUSTIFY L C R			TEXT MODE JUSTIFICATION XX "XX" XX "XX" XX XX "XX" XX "XX" XX XX "XX" XX "XX" XX																				

Annotating the drawing is typically done via a keyboard. It can also be performed by utilizing off-line text entry techniques or by incorporating standard, often-used notes in the symbol library. The result is a drawing, complete with symbols, notes, dimensions, and component characteristics.

Creating drawings is only one of the functions performed by CAD systems. A substantial part of total system productivity is in the editing or revision function. Since the original drawing file is resident on the disk (or may be retrieved from archival tape storage facilities), it is easy to call up a copy of that file into the active area of the disk for revisions or changes. These revisions are performed in much the same manner as was used in originally creating the drawing. Once done, the revised drawing may be stored as a revision copy, plotted and/or may replace the original drawing file.

A third major function of CAD systems is data extraction/processing, i.e., the input, storage, manipulation, and retrieval of non-graphic information. Most CAD systems provide some or all of the following subsidiary data extraction and data processing features:

- bill of materials,
- job accounting record,
- length, area, volume calculations,
- specifications,
- costs, and
- generation of numerical control tapes

This is only a partial list of what various CAD systems offer with respect to data extraction and data processing of graphic information. Another point to mention with respect to data base manipulation is the availability of both two and three dimensional data bases. Some CAD systems have the capability of working in a true 3D data base. Designers typically work in

two views, and changing the geometry of an object in one view automatically changes it in the other view. Each point in a 3D drawing file has an x,y,z coordinate. In addition, the user may design in any orthogonal view or in the isometric view. Hidden line removal may be done by various semi-automatic or interactive techniques, in which the portions of the drawing to be hidden are removed or changed to dashed line representations.

It is therefore obvious that CAD can be a very significant tool when integrated into a CAD/CAM manufactured housing facility.

CAD can be used as a design and presentation tool for graphic information, to store libraries of home design and details, and can serve a data extraction and processing function for both the business operations and manufacturing processes.

The typical stand-alone CAD system includes a CPU (central processing unit), mass information storage (disk and/or tape), a cathode ray tube (CRT), a graphic input device, an alpha-numeric keyboard, a function keyboard, and a graphic output device. In addition, the software is the set of computer instructions which completes the typical CAD system.

3.5.2 Software

The importance of available software as a component of a computer system should not be taken lightly. For example, the ability of a CAD system to generate a bill of materials makes it a very significant tool in pricing, cost control, and inventory control.

Software provides the series of computer instructions which activate and control various portions of the CAD hardware. The picture on the monitor is usually formed by implementing a series of software instructions. They position the cursor (the on-screen pointing device, eg., cross hairs or arrow) and cause lines, characters, and other symbols to be automatically drawn, connected, and modified to create a design.

Graphics operations often consist of considerably more than just drawing pictures. Pictures must be manipulated (enlarged, reduced, rotated, etc.) and, ultimately, used as part of an application process (perspectives, mechanical designs, shading, process control, or observing certain results). The software must also activate the various CAD input and output devices.

3.5.2.1 Generating Numerical Control Data

Some CAD systems have specialized microprogramming software packages which can do calculations, create geometry and generate numerical control data. Not only can this be a significant production tool, but due to the simplified programming these systems offer, numerical control can be used in conjunction with computer graphics to design and manufacture one-of-a-kind parts.

Numerical control is the concept of controlling processes by the use of numbers and symbols. The processes include material removal (cutting), material deformation (forming), or material handling (robotics). The procedure of translating geometric and functional requirements into instructions (numbers and symbols) acceptable to the process controller (machine control unit or MCU), is called numerical control programming. The numbers are usually derived from a blueprint or the database of a graphic geometric model. The symbols are a function of the make and model of the MCU. The numerical control program is then input to the MCU, which converts the instructions into machine motions and auxiliary functions.

There are a number of benefits which accrue from deriving the NC controls from the graphic information rather than from the older manual and language-based methods of NC programming. First the shared database, when properly created, eliminates the need for redefinition and reinterpretation of the part geometry. Second the ability to overlay the part, fixtures, tools, and toolpaths for visual verification of the correctness of the operation prevents major expensive errors from reaching the shop floor. Third the available graphics allow for the creation of complete pictorial instruction sequences of the operations for the machine tool setup person and operator.

When there is a direct relationship between the central computer NC commands and the machine tools, it is called direct numerical control (DNC).

In cases where the central data base becomes too large and complex, pre-programmed numerically controlled machines can read a bar code printed on a part to determine its manufacturing instructions separately. This greatly simplifies the central NC data base and allows for greater flexibility in re-programming various manufacturing processes. This is called computerized numerical control (CNC).

3.5.3 Hardware

Although the operation of CAD hardware is not directly related to CAM automated manufacturing processes, any implementation of CAD/CAM technology in the housing industry will present a proliferation of terms and concepts which may tend to confuse the untrained observer. For this reason, a brief description of CAD hardware appears in Appendix 1 of this report. The glossary of terms, found in Appendix 2, defines many of the unique terms likely to be encountered in the CAD/CAM industry.

4.0 THE GLOBAL CONTEXT

CAM manufactured housing is a relatively new concept with Japan and Sweden being the leading innovators in the field. Although their building concepts are quite different, the degree of automation is comparable. In the United States, the percentage of the housing market that is factory built far exceeds that in Japan (50% versus 17%), but the amount of factory automation in the U.S. and Canada is infinitesimal by comparison.

In Canada, this lack of advanced technology in manufactured housing is most likely due to the fact that the industry in Canada has grown out of the mobile home market and has always been associated with that product. As a result, a lack of acceptance of manufactured housing in the conventional marketplace has not permitted the industry to invest in research and development and factory automation.

Expenditures in these areas are not economically justified when the end product appeals only to the very lowest end of the housing market. The Japanese strategy by contrast, is that a factory built home is as good as a house built on-site; the industry has gone to considerable expense and effort to prove to the consumer that this is the case.

The economics of automated housing factories in North America, when building for the conventional housing market, are difficult to assess because there are no established precedents. However, the Lion Building Systems factory described in Section 2, although not yet operational, would appear to be a very viable business. With an investment of \$1.5 million, the factory could produce up to 400 housing units a year on a single shift, and could provide housing to builders at a cost of 10-15% less than conventional construction. The break-even point for this factory would be 60 houses per year.

In terms of the acceptance of the product by regulatory authorities, there is no reason why the automated factory could not meet the same acceptance criteria as any other factory built home. Although Canadian Standards

Association (CSA) acceptance of a factory is not required in all provinces, CSA's approach to the automated factory would be exactly as it is for any housing or component factory.

A CSA approved factory would have CSA inspectors going through the factory twelve times a year. Their mandate, as of 1981, is to inspect quality control and measure it against National Building Code standards. Their inspections are accepted by CMHC and are equivalent to the "ready for lath" inspection.

In a computerized factory the same standards would apply, but in a case when engineering analysis is being done by computer, CSA could retain a copy of the computer program in their vaults in Ottawa.

The acceptance of factory built housing by the consumer in the conventional housing market is a major problem in Canada. Factory built housing is usually associated with narrow metal boxes, with paneling on the interior, with exposed staples and joints on walls and ceilings, etc. It may be difficult to break down this barrier, but it is obvious from the manufactured housing in Japan, that factory built housing is truly of superior quality in finishes and detailing, and could compete with any house built on-site.

Automated housing factories are generally based upon panelized construction. This is because it is considerably less complicated to construct components in two dimensions, where the third dimension is a machine controlled function, rather than to program equipment to work in three dimensions. It is considerably more costly to equip a factory with machinery, i.e., robots, which work in three dimensions.

4.1 North America

CAM (Computer Aided Manufacturing) does exist in the North American housing industry. Some factories may use the odd machine which is operated and controlled by punch tape or cassette tape. Although this is a very limited

application of CAM technology, it is the stringing together of such cells, or machines, into an automated assembly line linked to a central computer, which is the CNC (Computerized Numerical Control) concept of factory automation.

It is the fact that these computerized manufacturing cells are isolated operations within a factory operation which distinguishes the North American manufactured housing industry from the automated factories of Japan and Sweden.

4.2 Japan

There is much to be learned from the Japanese manufactured housing industry. They have taken the automated factory to a stage of evolution which is beyond anything found elsewhere in the world.

The most sophisticated manufacturer in Japan is Sekisui Chemical Company. Whereas most manufacturers in Japan produce houses or components in the factory which represent anywhere from 10% to 55% of the completed house, Sekisui produces 80% of the completed house in the factory. It is able to produce a house every 40 minutes.

The main structural components of Sekisui's housing are welded steel frames which form a box, in six size variations. There are 100 wall variations with four external finish options to fit into the steel frame.

The units are conveyed along a 400 meter production line at a speed of 1.3 meters per minute; one unit is completed every four minutes. The production line consists of a main line and various sub-lines. On the main line the steel unit structure is fabricated by an automatic welding process and then the exterior wall panels and insulating materials are fitted. The floors, ceilings, column frames, wall panels and other fittings are fabricated on sub-lines and conveyed to specific points on the main line for installation. The whole process is computer controlled.

Kitchen cabinets, sinks, bath units and stairs are also made on sub-lines, transported to locations on the main line and installed.

One of the more significant concepts in this factory is that of zero inventory control. Sekisui maintains only a five day inventory of building materials. This reduces storage requirements and reduces financing charges on stored inventory.

Assembly of the housing unit is done by a five man team in five hours. The tolerance between the units is 2 mm, the same as required throughout the manufacturing process in the factory.

Once the units are assembled on-site, there remains some interior finishing to be done and the plumbing and electrical to be hooked up.

Although there is no direct link between CAD and CAM, CAD is used as a design, presentation and costing tool. Sekisui is presently working on setting up their factory as a true CAD/CAM operation, but feel that it will take four years to complete.

One of the roadblocks to further integration of computer technology is that it is likely to displace workers. The loyalty which Japanese industry has to its workers, and visa versa, precludes any drastic changes to factory operations.

Although many of the production concepts could be of significant benefit to the Canadian housing industry, the overall manufacturing system and product is not applicable to the Canadian market. There are a number of reasons why this is so.

One of the main reasons is that the systems are overly complex. This is not to say that the fine tolerances and attention to detail are not important and could not be duplicated in Canadian industry, but steel post and beam construction with infill panels of autoclaved lightweight concrete (ALC) would simply not work in Canada. ALC does not have a sufficiently high insulation value to meet Canadian standards. Thus, a very complicated and costly process would be required to produce a material which has a no more sophisticated function in the overall housing assembly than stucco. There are indications by Misawa Homes that work is being done on creating a structural insulated panel using ALC which could be considerably more practical in the Canadian market.

Also, aside from the fact that the steel frame would create thermal break and condensation problems, this structural approach is not nearly as sensible for the Canadian market as an approach based on wood panels.

There are some factories which are producing wood panels applicable to the Canadian scene. Misawa homes in Matsumoto and Kobori Juken in Shiga both produce wood stressed skin panels.

Misawa takes lumber from the top 20% (quality grades) of Canadian and U.S. production, air dries it for two months, kiln dries it, and then remills it to their own dimensions and tolerances. Then, on a computerized manufacturing line, they assemble open stressed skin panels with exterior finish and insulation, but no electrical or interior finish. The end panel has a tolerance of 1 mm in length and width, and 0.05 mm in thickness.

In Japan, the wood stressed skin panels are used as infill panels in a steel frame, whereas in Canada it would make more sense to use the panel as a structural wall in a panelized housing system. The advantage of stressed

skin panels over conventional wood frame panels is that less wood material can be used to meet the same structural requirements.

It is important to note that quality control standards for the raw materials is the only logical approach. When manufacturing equipment can work to such fine tolerances, it is logical to maintain a uniform quality standard for the raw materials.

Quality control is a natural spinoff of computerized manufacturing processes, because it is actually more difficult to program the equipment to accept less exacting tolerances.

4.3 Sweden

Sweden's approach to the automated factory is more relevant to the Canadian market than that of Japan, because Sweden produces a structural wood panel rather than infill panels for a steel post and beam structure. It is worth noting, however that panels are the basis of production in both the Swedish and Japanese factories. In some cases, though, the factories in Japan will apply the panels to the steel boxes and ship the boxes to site rather than ship the panels.

A further reason why the Swedish structural panel approach is more applicable to the Canadian market than the Japanese systems, is that it allows more design flexibility - in essence the same degree of flexibility as conventional construction. With the large distances which exist between market areas in Canada, it is more compact to ship stacked panels than to ship a "box of air."

In section 4 there is a detailed description of a Swedish housing system which is about to be imported into Canada. This section will describe some of the details of and variations to this system.

As with the Japanese case, there is no direct link between CAD and CAM, although both are being used in factories. Numerical Control (NC) information must be processed separately to run the automated equipment. One interesting function for which CAD is used in Sweden, is to determine the most efficient configuration for stacking panels in a container for overseas shipping.

There are two main wall panel approaches used in Sweden. One is the use of 1.2 metres wide wall components and the other is to construct continuous walls up to 10 metres long. The factory setup for a constant panel size will be less expensive, but the flexible panel size approach offers more design flexibility. The number of connections between panels is not an energy consideration because the gasketing system used for the joints is air tight.

The wall studs are generally composite studs with hardboard, dowel, or metal spacers. The reason for this approach is the tendency in Sweden to use much higher insulation values than those required in Canada and the resultant wall thickness required to provide the necessary insulation space.

The electrical work is generally done on site with electrical chases provided in the wall or floor panels. Heating systems are generally electric.

Rough-in plumbing is done in the factory and the plumbing wall is shipped to the site with one side open. One side is left open for shipping since Swedish building codes require on-site pressure testing of plumbing.

Although the transfer of this technology to Canada shows great promise, it must be related to the Canadian marketplace. Recent attempts to sell Swedish housing products in Canada have been relatively unsuccessful because Canadian design and marketing approaches have not been fully addressed.

5.0 COMPUTERS

Another major consideration when implementing imported technology or applying CAD/CAM or CAM to any Canadian manufacturing facility, is the choice of a computer system. There are problems associated with the use of European computer technology or the import of manufacturing systems based on European computer technology.

5.1 European Computers

European computers are not fully compatible with North American systems and in some cases, are not even close. Computer languages are much more likely to be fully compatible.

The preferred method for adapting the computer aspects of foreign housing systems is to program a North American computer with the software used on the foreign computer.

There are two less desirable alternatives. First, the complete computer system could be imported. The main problem with this approach is that servicing is a major consideration and there is simply not the technical support in Canada for European or Japanese computers. The second alternative is to choose a North American computer with the same operating system as the foreign computer. This may be difficult to do, since it may lead to not having the best computer technology, and, without the access codes to the computer program, it would be impossible to update the computer software in-house.

5.2 North American Computers

The CAD/CAM, CAE (Computer Aided Design/Computer Aided Manufacturing, Computer Aided Engineering) market is a very high growth and volatile sector of computer technology. All the major computer vendors have a range of products which can be applied to manufactured housing, and the complexity of such an integration would suggest that a well established computer vendor is required to provide the technical support, service, and product update necessary.

The choice of a computer system is a very complex decision. Although it is not limited to the major vendors, they are far enough ahead in the marketplace and are putting so much money back into research and development, that if technological innovation does not come internally they are not far behind in responding. Computer technology is advancing so rapidly that when making a choice it is not only important to know what is available today, but where the market is going.

The major CAD/CAM, CAE vendors can also be seen as a major information resource in regard to understanding the technology; they tend to be very helpful in this respect.

The following information on the top ten North American CAD/CAM, CAE vendors was provided by Daratech, Inc. of Cambridge, Mass., a computer research firm. The information was taken from their December 20, 1984 News Release. The CAD/CAM, CAE information which would have the most relevance to a CAD/CAM housing factory is highlighted.

Although a very cursory look at the leading CAD/CAM, CAE vendors it serves to illustrate the complexity of the marketplace and of the computer decision.

Daratech's new survey analyzed 100 vendors and a total of 236 systems. For each company a listing of products, services, and markets served is provided. Background on the company, current sales data, and a breakdown of sales according to market segment are also provided. In addition, there are sections on R&D, marketing, and manufacturing resources. In-depth descriptions cover each company's product line.

Entitled CAD/CAM, CAE: Survey, Review and Buyer's Guide, the survey costs \$368 for a one-year subscription, and is available from Daratech, Inc., 16 Myrtle Avenue, P.O. Box 410, Cambridge, MA 02238 (telephone 617/354-2339).

With annual revenues of U.S. vendors estimated at more than \$2.7 billion, annual growth for 1984 has skyrocketed to 50 percent -- up from 40 percent in 1983, and 28 percent in 1982. This high growth, most of it experienced in the first half of 1985, follows the introduction, late in 1983, of a generation of more powerful, cost-effective CAD/CAM, CAE systems by each of the five market leaders -- Computervision, IBM, Intergraph, Calma, and McAuto. The growth has been fueled by the willingness of an increasing number of corporations to make substantial investments in design and manufacturing automation tools.

Computervision

Computervision's strategy is to bring to market an array of hardware and software that profile focused, industry-specific CAD/CAM, CAE solutions over a spectrum of price and performance. In the software area, Computervision intends to continue to develop key graphics and applications packages in-house, but will look to outside vendors for speciality applications packages and operating software.

This strategy appears to have paid off in 1984. However, Daratech believes Computervision's resources may be spread too thin in 1986 as it tries to support its diverse product line in the field, and at the same time update its current CDS 4000 products which, by the end of 1985, will probably lack the performance to maintain their competitive edge. Thus, for Computervision to hold its narrow lead over IBM, the company's new products, particularly the Sun-based CDS 3000 and the IBM-based CDS 5000 lines, will have to gain substantial market acceptance very rapidly.

IBM

IBM, whose sales of CAD/CAM, CAE systems to end users grew at an estimated annual rate of almost 60 percent in 1984, is forecast to increase its overall market share to a little over 19 percent in 1985. Widely expected to surpass Computervision, IBM -- the market leader in the mechanical and manufacturing segment -- remains a fraction of a point behind because of Computervision's stronger-than-expected sales.

IBM continues to aggressively build its CAD/CAM, CAE product line with a steady stream of new products. The 15.3 percent price cuts on Model 4331 and Model 4361 computers announced in September, makes IBM a strong challenger for the number one spot in the CAD/CAM, CAE industry in 1985.

Intergraph

Intergraph -- the third ranked CAD/CAM, CAE company after Computervision and IBM -- increased its revenues by more than 71 percent in the first nine months of 1984 compared to the same period for the previous year, and continues to gobble up market share. According to Daratech, Intergraph's revenues will approximate \$402 million in 1984, giving the company a 15 percent market share for that year, one percentage point more than is experienced in 1983.

The company's outstanding success is due in part to its unique ability to correctly anticipate market needs, to turn these needs into deliverable, cost-effective products and consistently bring them to market at the right time.

In a departure from its previous practice of basing its systems exclusively on Digital Equipment Corporation's general-purpose computers, Intergraph, in early 1985, announced a new engineering workstation incorporating National Semiconductor Corporation's 32032 microprocessor. Called Interpro 32, the new \$20 000 workstation can operate a 32-bit general-purpose computer that runs third-party software under the UNIX 4.2bsd operating system, or as an IBM-compatible personal computer. Interpro 32 can also function as a workstation on existing Intergraph CAD/CAM, CAE systems.

Calma

Previously strong in the traditional electronics CAD/CAM applications area, CALMA, by its own admission, has let the electronics side of its business slide while emphasizing mechanical and manufacturing applications.

McAuto

McAuto (McDonnell Douglas Automation Company) is challenging Applicon for fifth place in the CAD/CAM, CAE industry. In the mechanical and manufacturing segment, the area in which McAuto is strongest, the company trails IBM, Computervision, and Calma with 6 percent share of the market.

In December 1984, McAuto announced it had signed a value-added resellers agreement with IBM and intended to market turnkey Unigraphics II systems using IBM Model 4361 mainframe, VM/SP operating software, and IBM Model 5080 workstations. These systems will augment McAuto's existing product line, which uses computers manufactured by Digital Equipment Corporation and Data General.

The company is moving to modernize its workstation products with tabletop, dual-monitor units based on Megatek's high-performance MERLIN terminals.

Unigraphics II, McAuto's upgraded CAD/CAM software that was introduced in the spring of 1984, appears to be gaining wider user acceptance. CAM remains McAuto's strength in the market, and although competitive systems, particularly those of Computervision, Prime and CADLINC, have made progress in this area, McAuto feels it still has the technological edge. According to a company spokesman, people that choose Unigraphics II are doing so because of the product's database structure and NC capabilities.

Applicon

Applicon -- the Schlumberger N.V. subsidiary that in 1981 was the number three CAD/CAM, CAE company behind Computervision and Calma -- is working to regain lost ground.

Failure to fully update its product line is probably the major reason for the company's recent decline in market share. BRAVO, Applicon's much heralded system for mechanical design, was almost two years late in coming to market. Today, with a little over three hundred BRAVO systems installed, marketing and sales will have to be stepped up for BRAVO so that it can reach its full sales potential.

Control Data

Control Data is fighting to gain more recognition in CAD/CAM, CAE markets. It has focused much of its turnkey system and service-related activities in the CIM division in November 1983, and continues to build its CIM sales force and extend its product line.

The company's CAD/CAM, CAE revenues arise principally from medium-sized system sales. ICEM 800 series configurations with 15 workstations or fewer have proven to be the company's best sellers. A typical ICEM 800 with twelve workstations sells for about \$860 000. Control Data's strategy is to act as a systems integrator, offering a combination of systems and timeshare services that bring together multiple engineering and manufacturing functions.

Auto-Trol

After three years of losses and two years of declining revenues, Auto-trol, in 1984 has made a remarkable comeback.

Auto-trol's success is principally due to acceptance by the market of its Apollo-based AGW workstation products, and a lot of marketing hustle reminiscent of the company's glory days before 1980. Indeed, Daratech estimates that 1984 revenues will top \$70 million, enough to share a 3 percent share of the overall market.

In a move to expand the company's product offering beyond engineering and architectural design/drafting, Auto-trol has begun to introduce analytical software packages that give its product line a CAE dimension. Typical of these is STEEL-3D, a package for the interactive design and analysis of steel frame structures, and PLAN, a drafting package for the creation and analysis of architectural floor plans.

5.3 The Computer Choice

The choice of a computer system should not be taken lightly. As the above information illustrates, the computer marketplace is a very dynamic and complex entity. I have personally seen a case where a house manufacturing facility bought a turnkey CAD system for which they spent twice what they needed to spend and which is missing some key functions which would have been of major benefit to their operation.

The process of choosing a CAD/CAM computer system is very complicated. Not only can much information be derived from sources such as Daratech and from computer vendors, but most provinces have CAD/CAM centers which can help considerably in making the proper choices. They not only have access to current information on CAD/CAM technology, but can be very helpful in setting the proper course for integrating the technology into existing or proposed house manufacturing facilities. A list of Canadian CAD/CAM centers appears in Appendix 3.

A list of publications which may be useful as an information resource appears in Appendix 4.

6.0 THE RECOGNITION OF NEED FOR CAD/CAM AND POSSIBLE BENEFITS

When contemplating constructing a manufactured housing facility, or implementing advanced technology within an existing manufacturing facility, questions may arise as to whether or not CAD/CAM technology is required.

The recognition of the need for CAD/CAM begins with an internal assessment of products, engineering applications, work loading, staff, and information flow.

The recognition of need focuses on two interrelated areas: engineering design/drafting, and manufacturing. A CAD/CAM turnkey system can provide payoffs in one or both areas.

In addition to internally derived requirements, the need for CAD/CAM may be driven by external forces such as shortened business cycles, customer requirements, and market demands. It is important to recognize and reconcile conflicting needs that may occur when both internal and external requirements are considered.

6.1 Preliminary Recognition of Need

A general assessment of engineering design/drafting and manufacturing will provide an initial indication of the viability of CAD/CAM. The following questions should be asked by the potential buyer:

6.1.1 Engineering design/drafting

- Do you modify large numbers of existing drawings to produce new versions of houses?
- Do you perform large numbers of engineering changes to drawings?
- Do you make use of 'standard' components in new house designs?
- Are you moving toward families of custom houses in which features are selected from standard components?
- Has your market window and product life cycle been shortened over the past five years?
- Is the number of drawings you produce each year increasing? Can the drafting group keep up with the load?
- Is the need for supplementary design information (e.g., bill of materials, parts list, test results, customer order information) outstripping your ability to generate or collect it?

In addition to design drafting related issues, the increasing use of Computer Aided Engineering (CAE) systems results in the following questions:

- Can more comprehensive engineering analysis result in product cost reduction or design optimization?
- Can computer based analysis/simulation reduce prototyping costs and shorten overall concept to market introduction time?
- Will CAE and CAD improve product quality and reliability?

6.1.2 Manufacturing

- Are you continually requesting design changes so that a component can be effectively manufactured?
- Is there need for improvement in communication between engineers and manufacturers?
- Is it becoming increasingly difficult to design tooling and fixtures as product designs become more complex?
- Do you use programmable automation, i.e., numerical control machines?
- Do you program automated equipment manually? With NC programming languages?
- Is the need for supplementary manufacturing information (e.g., bill of materials, parts list, test results, customer order information) outstripping your ability to generate or collect it?

An affirmative answer to a majority of the questions set out above should lead to a further investigation of the benefits of CAD/CAM technology.

6.2 Benefits

Some of the benefits which can be derived from the implementation of CAD/CAM technology are as follows:

Cost Issues

- lower cost per drawing or NC tape because of measurable increases in productivity;
- lower cost for design revisions, custom design;
- stabilization in work force due to fluctuations in engineering loading;

Time Related Issues

- shorter time required to bring a new product to the production ready state;
- shorter time to incorporate design change;
- shorter time to develop fixtures/tooling;
- reduced "communication time" between engineers and drafters, engineers and manufacturers;
- less time spent on standard compliance;

Technical Issues

- better design quality because of greater likelihood for consideration of alternatives;
- better analysis pre- and post-processing
- potential for earlier discovery of tolerancing error, reproductivity anomalies, design inconsistency;
- better transferability of design among geographically separate departments;
- more uniformity in design representations.

7.0 ANALYSIS

The implementation of advanced technology into a low technology industry such as the housing industry is a very complex process. Often the use of technology in a production or engineering process requires users to "think differently." For example, CAD designers can change scales of drawings very easily instead of redrawing; in the automated factory, production technology can perform many functions at once with great accuracy instead of using old processes of sequential assembly lines with a quality control process at the end.

The implementation of advanced technology in the housing industry requires a full understanding of CAD/CAM technology and automated manufacturing concepts. This may require a team approach which brings together the expertise of technical people, designers and the manufacturer or builder.

One of the fundamental guidelines of an analysis process for employing advanced technology is that technology implementation must be financially motivated and not technology for technology's sake. For this reason the "Driving Factor Method" described below is used to perform a needs analysis of a housing manufacturing operation and to identify appropriate technology that can be justified to meet specific objectives.

The "Driving Factor Method" is composed of the following steps:

- 1) needs analysis,
- 2) technologies benefits; and
- 3) translation of needs into technical solutions.

7.1 Needs Analysis

The first step is to identify, quantify and establish priority in the manual or normal house manufacturing functions which cost the most in an operation. This cost factor can be made up of many components as follows:

- overall labor;
- rework;
- material handling labor;
- material costs;
- inventory carrying costs;
- wastage of materials; and
- energy costs.

The objective here is to quantify costs per standard unit and to understand the interrelationship of these factors. For example, overall labour may be 25 percent of the direct house costs, or 35 percent of the labour is spent on material handling instead of performing the actual labour function. This step assists management in understanding which areas of costs should be reduced.

Another way to help focus on the central issues of a needs analysis is to answer the following questions:

- What are the present problems and bottlenecks of existing house manufacturing operations?
- What are your needs over the next 3 to 5 years?
- Where are the main areas for improved quality?
- Out of a list of all house manufacturing steps, which ones involve more labour, material, wastage of time, wastage of material, etc.?
- Which parts are the heaviest, largest, and of the highest volume?
- If quality and timelines of production is greatly increased, how will it affect the revenues and bottomline?

Answering these questions and performing a cost analysis will assist in setting priorities for productivity improvement areas. Up to now, technology and its benefits have been ignored so an objective picture of costs can be identified.

A first level analysis of a list of house manufacturing processes produces a list of needs as follows:

- labour intensive processes include nailing, cutting, and material handling of wall, ceiling and floor units
- a large inventory is required to handle the many design systems for each house
- inside of house quality and aesthetics is important
- paperwork and material flow patterns are fairly intricate for building semi-custom designs

7.2 Technologies and Benefits

The previous sections of this report have briefly discussed the technologies applicable to house manufacturing and their benefits. Below is a list of mature technologies which can be used in house manufacturing.

1. Robotics: Applications include cutting of panels, painting of wall sections, assembly of blocking and eave details, and handling of wall units in a work cell.
2. Cutters, jointers, etc.: Applications include automated and precision cutting functions such as laser and water cutting which can perform cutting tasks not possible with standard technologies.

3. AMR Systems: (Automated Material Reporting System): An example is bar coding which enables computerized tracking of house parts and assemblies and work performed on these assemblies. Using this technique, instantaneous printouts are available of the level of inventory, where it is and the completion status of each job.
4. AMH: (Automated Material Handling Systems): Various types of systems can be utilized for the movement of materials once the driving factors have been identified. As an example, labour could be reduced through the use of an overhead crane system for the movement of heavy material. In the situation where material movement was excessive for a particular function, such as a window installation, an AMH system could be installed to eliminate the labour involved. These systems could easily be interfaced with much of the mechanization equipment used in assembly lines today.
5. Cells: When a high cost area has been recognized and defined, it is then necessary to further define whether the function should be performed on a sub-assembly basis or integrated into a cell function. The cell function can be viewed from three perspectives.

First, a cell can be a single function where a specific job is handled like putting a window module in an opening and securing it. Second, a cell could be a multi-function operation where various sub-assembly lines merge into the cell for a specific work item to be performed and then merge back into their separate sub-assembly lines. An example would be one cell to do gluing and another to do only nailing. Third, a cell can be multi-tasking where several functions are performed on one assembly. An example of this is one robot feeding multiple house parts to painters, nailers and finishers all at once. It takes careful analysis to determine the type of cell to implement.

7.3 Translation of Needs to Technical Solutions

A key part of the final decision making process is the setting of priorities and the weighting of 'criteria'. Examples of obvious business decision making criteria are listed below:

1. capital costs
2. operational costs
3. return on investment
4. risk
5. technical performance requirements?
6. impact on existing labour and methods
7. timing of delivery and installation
8. business objectives and the major needs or driving factors

By using a matrix, the selected technologies would be individually weighed against each of the criteria.

From a first level analysis, the following technologies have merit.

1. A Manufacturing Resource Planning (MRP) system would definitely be necessary to manage the house parts ordering, inventory control, work in progress, process planning and scheduling of production. Paperflow would be controlled so custom houses can be efficiently manufactured with the required pieces always available.
2. Material handling systems would reduce part handling and would feed the mechanization or automated work stations such as gluing, curing, nailing, etc.

3. Proven cutting systems (water and laser) would be used to automatically cut wall, floor and ceiling lengths to shape with window and wet core cutouts. These systems would treat all wall or ceiling pieces as a 2 dimensional part.
4. Bar coding systems enable fabricated parts to be easily labelled and identified so automatic processes can be performed down the line. For example, paint colour selection and window opening options could be performed automatically.

This analysis procedure works well in most industries and will work well in the house manufacturing industry. For this report a very brief needs analysis was performed, but considerably more detail would be required when actually applying this process in a real situation.

8.0 RECOMMENDATIONS

This report is not a complete "how to" study on the implementation of CAD/CAM technology. This is a very complex subject which involves the integration of changing technology with a very intricate and dynamic marketplace. The following recommendations are intended as general guidelines and are not in any particular order of priority.

1. Search the analogous type of operations such as trailer, R.V.'s modular home manufacturers, as well as similar advanced automated home manufacturers in Japan. Document their type of mechanization/automation and identify their problem areas. It is anticipated that concepts can be borrowed and adapted from existing industries.
2. Search other industries for the latest in mechanization, automation, CAD & CAM operations.

3. Model and simulate the entire process. This can be accomplished on several available systems in use today.

Three computerized factory modelling packages for manufacturing operations are available from Prikster and Associates, SMI Inc., and See Why (Woods Gordon) and are used today to design, optimize and analyze the design of complex manufacturing operations. These systems can simulate the fabrication and assembly operations in a manufacturing plant. They enable a user to perform complete plant and layout design. The performance of each machine and operation is defined in the computer, and the operator can actually see how parts are handled in each process and how they are transferred to the next process. Bottlenecks, operation statistics, start-up procedures and simulated faults can be identified.

4. Set up a pilot plant. There are many new concepts to be tried and proven which may cause time delays. Begin the pilot plant on a semi-automated basis and establish basic concepts first, e.g., develop the panels, and then move on and implement individual automation processes. Once an adequate profit and quality level has been reached, the pilot plant can then be scaled up. The small plant can test new technology applications as well as the large plant. Because there are no automated house manufacturing facilities in Canada, any factory of this type is a pilot plant and technological implementation must occur in a logical progression. It is important to remember, also, that technology is developing at a very rapid pace, and the introduction of any technological innovation should not eliminate the possibility of employing further advances in technology.

5. Simulate individual major components such as the basic wall panel - this could be simulated as a vertical wall. Then, move through all the required cells of technology such as the cutting, finishing, blocking, windows, electrical and plumbing, insulating, etc. This will allow the engineer to determine what steps should be automated and what should be left manual at this time.
6. A good component tracking system must be included from the very start if initial and ongoing performance is to be measured. The most effective method at the present time is, probably, the bar code system. This system is able to feed the data back to the inventory system as well as to the production data base system for correlation with the customers' requirements.
7. A production data base system will be large and complex. It may take a year or more to set up. It should be connected with the engineering data base in order to provide a direct relationship between production and the customers needs.
8. As many parts and processes as possible should be standardized.
9. Less quality control will be needed if key automation steps are implemented.
10. Subcontract out non-standard parts, or those that cannot be made profitably, such as windows which are already made through automated techniques.
11. Identify standard home components that are not acceptable to an automation technique and must be redesigned.
12. Identify new construction components that will be required.

9.0 CONCLUSION

The Canadian housing industry is severely depressed and the manufactured housing industry is even more so. It will recover, and in doing so, the opportunity exists to apply state-of-the-art technology to creating a housing product which is less expensive, of better quality and produced in a fraction of the time required for conventional housing, and which is geared to the North American economy and marketplace.

Computer Aided Manufacturing housing technology exists in Sweden and Japan, and can easily be adapted to the Canadian context. U.S. computer technology is very advanced and continues to develop at a very rapid pace. The integration of these technologies would not only produce a housing factory which far exceeds anything presently in operation in North America, but would also leave room for the development of technological innovations which would be at the forefront of housing technology.

There are many opportunities for Canada to develop unique approaches to automated manufacturing in housing based on available technology. The integration of CAD software for design drafting, 3D modelling for marketing, energy efficient design, inventory control, design modification, and engineering, would be of significant benefit to the housing industry in general. The ability to generate numerical controls directly from this information, would be a significant technological advance towards the automated factory of the future.

The approach taken by Lion Building Systems Inc., in adapting Swedish technology to the Canadian marketplace is a significant step in the right direction but there are many more examples of automated housing factories in the world which can be utilized in the same fashion. The likely outcome of such an integration is that Canada could have a much more progressive housing industry, and eventually be able to market its own products and technology in the global marketplace.

The existing Canadian home manufacturing industry is so basic, that, although individual manufacturing cells can be "CAM'ed" as discussed in Section 7, it is important to study such an integration within the context of the total operation and with an understanding of what technology is available and where technology is headed. Otherwise, existing manufacturers will not be able to compete with the inevitable influx of more progressive manufacturers who will spring up as the economy recovers. Not only are companies like Lion Building Systems Inc. importing advanced technology, but Swedish and Japanese manufacturers are seriously looking to market their technology in North America.

The development of an automated housing factory is not a simple undertaking. Neither the Japanese nor the Swedes have "the" answer for the Canadian market - they just have some of the answer. There is much room for technological innovation in manufactured housing to produce a uniquely Canadian approach and, in fact, there is nothing to prevent the development of a truly Canadian automated housing factory with the technology of the rest of the world acting only as a point of reference. It is necessary, however, to understand the tools available.

APPENDIX 1 CAD HARDWARE

COMPUTER HARDWARE

INFORMATION PROCESSING

THE CENTRAL PROCESSING UNIT

The Central Processing Unit (CPU) is the brain of the computer. It controls the retrieval, decoding, and processing of information, as well as the interpretation of operating instructions. In other words, the CPU contains the electronic logic which actually receives individual instructions, and causes the events specified by the instructions to occur.

MEMORY

The memory is where the program and data are stored. The CPU is not large enough to store all of the instructions it will have to execute, so these are stored external to it in memory chips. There are two kinds of memory chips: ROM and RAM.

ROM stands for "Read Only Memory." Information stored there is non-erasable and can only be read. This is a permanent set of instructions and data. ROM is used as a start-up code when the machine is first turned on. Generally, the ROM programming (or code) will allow the CPU to advance to some state in which it is referencing a keyboard in order to find out what the user wants it to do next.

The user will probably want to load and execute some application program. From some outside source, the user will cause that program to be loaded into the "Random Access Memory" (RAM). This memory can be used to read or write data and program files.

THE GRAPHIC PROCESSOR

The graphic processor and the graphic monitor determine the quality of the monitor image. The processor translates the data base image in memory for display on the monitor. If either of these devices has poor resolution the image will not be clear. This is a significant consideration when purchasing a microcomputer based CAD system.

INFORMATION STORAGE

The random access memory typically available on a computer, is not large enough to store the quantity of information generally required in a data file. There are special devices that can store large data files with ease. This data can be transferred to and from the computer memory as required.

A computer can store data files on tape (cassette or reel to reel), floppy disks, or hard disk units. They all store information on a magnetic surface, much as tape cassette players record music on the magnetic surface of a tape cassette. Each type of magnetic surface must be mounted in a special drive unit that contains mechanisms required to read information off the magnetic surface or write information onto it.

Tape cassettes are adequate only for small microcomputer systems handling simple functions. For intermediate functions, diskettes are preferred. Complex functions can use more sophisticated diskette drives with large data storage capacity, or hard disks.

TAPES

Some big computers store information on large reels of magnetic tape, but magnetic tape units are used, in most systems, only to back up hard disks.

FLOPPY DISKS

A floppy disk is a disk made of materials similar to magnetic tape. Floppy disks come in three sizes: 8 inch, 5 1/4 inch and 3 1/4 inch diameter. The diskette spins inside a disk drive, and a moving arm precisely positions a read and write head at any point on the diskette surface to which access is sought. Therefore, any part of the diskette surface is possible.

HARD DISKS

If a floppy disk does not hold enough information for operations, or if too much time is required to get at the information, a hard disk should be considered. This is a solid metal disk with magnetic coatings on one or both surfaces. Information is written on this magnetic surface in much the same way as it is written on a floppy disk. Five million characters (bytes) to over one hundred fifty million characters of information can be stored on a hard disk. The hard disk is mounted in a disk drive which spins it at very high speed. This allows one to gain access to any location on the disk surface in thousandths of a second. Characters can be written onto the disk, or read from it, at rates of approximately one million characters (bytes) per second.

Hard disks are mounted in two types of disk drives:

- 1) removable cartridge disk drives; and
- 2) winchester disk drives.

Removable cartridge disk drives, as the name implies, house the hard disk in a special cartridge container which can be removed from the disk drive. Therefore, one can store a lot of information on different cartridge disks, just as one can on different floppy disks or cassette tapes.

Winchester disk drives, on the other hand, have a rigid disk permanently sealed inside the drive, and therefore, can never be removed. The capacity of the one sealed rigid disk is fixed and may be anywhere from 5 to 150 megabytes. Winchester disk drives are, however, less expensive than removable cartridge disk drives.

THE TERMINAL

The terminal consists of graphic input devices, an alphanumeric keyboard, a function keyboard, and usually a digitizing surface. The feedback mechanism that shows the operator what is happening is a graphic display terminal or cathode ray tube (CRT).

DATA INPUT

There are two primary steps to data input: cursor movement, and command or data entry. The cursor indicates the point on the graphic display at which the next operation is to occur and the command or data entry indicates what is to take place at that point. The cursor may be indicated by cross hairs, an arrow, or a small "x" on the monitor.

These input functions may all be executed through the use of the alphanumeric keyboard, or may involve the use of a number of different input devices in various configurations.

THE KEYBOARD

The alphanumeric keyboard is a work station device consisting of a typewriter-like keyboard which allows the designer to communicate with the system using "English-like" command language. It contains letters, digits, and special commands which are machine-processable. While most CAD systems would allow all graphic commands to be carried out on the keyboard, most systems allow for other input devices to perform commands as this is generally faster and requires fewer operations.

CURSOR MOVEMENT

The cursor is a crosshair or pointer which appears on the graphic display terminal and is used to indicate the location at which a graphic operation is to occur, or is used for data entry in systems which have an on screen menu (locations on the screen which denote the function to be performed).

There are various devices to facilitate the cursor movement on the screen. The mouse is a device which, when rolled across a flat surface, duplicates the movement along that surface onto the display screen. Track balls and joysticks generate horizontal and vertical movements of the cursor on the screen. Data tablets transmit the location of an electronic pen when pressed on the tablet surface. Touch pens and light pens enter data points directly onto the display screens, but their use can be very tiring because they require the operator to hold his/her hand in the air for extended periods of time.

DATA ENTRY

Once the operator has pointed to a location on the display, the computer must then be told what to do with that point. Commands can be typed into the alphanumeric keyboard, but this tends to be a very slow operation. There are various hardware devices available which allow the operation to perform a single function or series of commands in a one step operation. These devices are generally based in some form on the use of a menu, located on a digitizing tablet or on the screen which, when activated, instructs the computer to perform a certain function.

The digitizing tablet is an electronically sensitized surface comprising a rectangular grid of lines which produces signals to the computer according to the position of the stylus pen placed upon it. In addition to its use with the menu, it is used to convert graphic information from existing drawings into digital signals so that the co-ordinates can be input to the computer or displayed on the monitor.

There are various approaches to data entry and when a choice exists, personal preference is a significant factor.

Menus may be on screen or on a digitizing tablet or both, or may be combined with a function keyboard which is independent of the alphanumeric keyboard. In the latter case, individual keys are programmed for specific graphic functions.

GRAPHIC DISPLAY TERMINALS

There are three principal types of graphic display used in CAD today. They are storage tube, refresh and raster display.

STORAGE TUBE

The storage tube retains an image continuously for a considerable period of time without redrawing (refreshing) being required. The image will not flicker regardless of how much information is displayed. However, the display tends to be slow relative to raster; the display is monochromatic; and, no single element by itself can be modified or deleted without redrawing.

REFRESH OR VECTOR REFRESH

The technology involves frequent redrawing of an image displayed on a CRT to keep it bright, crisp, and clear. Refresh permits a high degree of movement in the displayed image, as well as high resolution. Selective erase or

editing is possible at anytime without erasing and repainting the entire image. Although substantial amounts of high speed memory are required, large, complex images may flicker.

RASTER SCAN DISPLAY

Raster scan is the dominant technology in CAD graphic displays. Similar to conventional television, it involves a line by line sweep across the CRT surface to generate an image. Raster scan features include: good brightness, accuracy, selective erase, dynamic motion capabilities, and the opportunity for unlimited color. The device displays a large amount of information without flicker, although resolution is not as good as with storage tube displays.

TEXT MONITOR

Some CAD systems have separate raster displays for monitoring text functions. The advantage of this approach is that the graphic display is kept clear of non-graphic information.

OUTPUT DEVICES

There are a number of types of output devices available to generate hard copies of graphic information. There are pen plotters and electrostatic plotters which produce a scale drawing of the graphic information. There are also photo output devices which produce a non scalar photographic image of what appears on the display.

The hard copy serves only as a presentation medium for the graphic information for the purpose of marketing, checking, and technical presentation. The major output for the manufacturing process in a CAD/CAM operation is the NC data.

APPENDIX 2 GLOSSARY OF TERMS

GLOSSARY OF TERMS

AGV (automated guided vehicles)

AI (artificial intelligence). AI is the discipline of computer science dedicated to the concept that computers can be more intelligent, rather than to simulate intelligence.

AMH (automatic material handling).

Application Program (or package). A computer program or collection of programs to perform a task or tasks specific to a particular user's need or class of needs. For example, there are mechanical, electrical, architectural, space planning, construction applications, etc.

AS/AR (automatic storage/automatic retrieval).

Automated Drafting System. A computer-based system designed primarily to automate the process of drafting. Design capabilities are not included.

Automatic Dimensioning. A CAD capability that computes the dimensions in a displayed design, or in a designated section, and automatically places dimensions, dimensional lines, and arrowheads where required. In the case of mapping, this capability labels the linear feature with length and azimuth.

Batch Processing. The technique of processing an entire group (batch) of similar or related jobs or input items on a system at one time without operator interaction. This is in contrast to interactive graphics system.

Benchmark. The program(s) used to test, compare, and evaluate in real time the performance of various CAD/CAM systems prior to selection and purchase. A synthetic benchmark has preestablished parameters designed to exercise a set of system features and resources. A live benchmark is drawn from the prospective user's workload as a model of the entire workload.

Bill of Materials (BOM). A listing of all the subassemblies, parts, materials, and quantities required to manufacture one assembled product or part, or to build a plant. A BOM can be generated automatically on a CAD/CAM system.

Bit. The smallest unit of information that can be stored and processed by a digital computer. A bit may assume only one of two values: 0 or 1 (i.e., ON/OFF or YES/NO). Bits are organized into larger units called words for access by computer instructions.

Computers are often categorized by word size in bits, i.e., the maximum word size that can be processed as a unit during an instruction cycle (e.g., 16-bit computers or 32-bit computers). The number of bits in a word is an indication of the processing power of the system, especially for calculations or for high-precision data.

Bulk Memory. A memory device for storing a large amount of data, e.g., disk drum, or magnetic tape. It is not randomly accessible like the main memory.

Byte. A sequence of adjacent bits, usually eight, sixteen or thirty-two representing a character that is operated on as a unit. A Byte is usually shorter than a word and is a measure of the memory capacity of a system, or of an individual storage unit (as a 300-million-byte disk).

CAD (computer-aided design). A process which uses a computer system to assist in the creation, modification, and display of a design.

CAD/CAM (computer-aided design/computer-aided manufacturing). Refers to the integration of computers into the entire design-to-fabrication cycle of a product or plant.

CAM (computer-aided manufacturing). The use of computer and digital technology to generate manufacturing-oriented data. Data drawn from a CAD/CAM data base can assist in or control a portion or all of a manufacturing process, including numerically controlled machines, computer-assisted parts programming, computer-assisted process planning, robotics, and programmable logic controllers. CAM can involve: production programming, manufacturing engineering, industrial engineering, facilities engineering, and reliability engineering (quality control). CAM techniques can be used to produce process plans for fabricating a complete assembly; to program robots; and to co-ordinate plant operation.

CAT (computer automated testing).

Cathode-Ray Tube (CRT). CRT is the principal component in a CAD display device. A CRT displays graphic representations of geometric entities and designs and can be of various types: storage tube, raster scan, or refresh. These tubes create images by means of a controllable beam of electrons striking a screen. The term CRT is often used to denote the entire display device. See also performance, CRT.

Central Processing Unit (CPU). The CPU is the computer brain of a CAD/CAM system. It controls the retrieval, decoding, and processing of information, as well as the interpretation and execution of operating instructions - the building blocks of application and other computer programs. A CPU comprises arithmetic, control, and logic elements.

CIM (computer integrated manufacturing). CIM is a concept of a totally automated factory in which all manufacturing information and materials are integrated and controlled by a CAD/CAM system. CIM enables production planners, schedules, shop floor foremen, and accountants to use the same data base as product designers and engineers.

CNC (computerized numerical control). CNC is a technique whereby a machine tool control uses a computer to store NC instructions generated earlier by a CAD/CAM system.

Colour Display. A CAD/CAM display device. Colour raster-scan displays offer a variety of user-selectable, and contrast colours to make it easier to discriminate among various groups of design elements on different layers of a large, complex design. Colour speeds up the recognition of specific areas and subassemblies, helps the designer interpret complex surfaces, and highlights interference problems. Colour displays can be of the penetration type, in which various phosphor layers give off different colors (refresh display), or the TV-type with red, blue, and green electron guns (raster-scan display).

Command. A control signal or instruction to a CPU or graphics processor, commonly initiated by means of a menu/tablet and electronic pen or by an alphanumeric keyboard.

Compatibility. The ability of a particular hardware module or software program, code, or language to be used in a CAD/CAM system without prior modification or special interfaces. Upward compatible denotes the ability of a system to interface with new hardware or software modules or enhancements (i.e., the system vendor provides with each new module a reasonable means of transferring data, programs, and operator skills from the user's present system to the new enhancements).

Computer Graphics. A general term encompassing any discipline or activity that uses computers to generate, process and display graphic images. It is the essential technology of CAD/CAM systems. See also CAD.

Configuration. A particular combination of a computer, software and hardware modules, and peripherals at a single installation and interconnected in such a way as to support certain application(s).

Cursor. A visual tracking symbol, usually an underline or crosshairs, for indicating a location or entity selection on the CRT display. A text cursor indicates the alphanumeric input; a graphics cursor indicates the next geometric input. A cursor is guided by an electronic or light pen, joystick, keyboard, etc., and follows every movement of the input device.

Crosshairs. Moveable horizontal and vertical lines used to define point location on a graphic CRT. Also, graphic cursor.

Data Base. A comprehensive collection of interrelated information stored on some kind of mass data storage device, usually a disk. Generally consists of information organized into a number of fixed-format record types with logical links between associated records. Typically includes operating system instructions, standard parts libraries, completed designs and documentation, source code, graphic and application programs, as well as current user tasks in progress.

Data Tablet. A CAD/CAM input device that allows the designer to communicate with the system by placing an electronic pen or stylus on the tablet surface. There is a direct correspondence between positions on the tablet and addressable points on the display surface of the CRT. Typically used for indicating positions on the CRT, for digitizing input of drawings, or for menu selection. See also graphic tablet.

Design File. Collection of information in a CAD data base which relates to a single design project and can be directly accessed as a separate file.

Digitizer. A CAD input device consisting of a data tablet on which is mounted the drawing or design to be digitized into the system. The designer moves a puck or electronic pen to selected points on the drawing and enters co-ordinate data for lines and shapes by simply pressing down the digitize button with the puck or pen.

Dimensioning, Automatic. A CAD capability that will automatically compute and insert the dimensions of a design or drawing, or a designated section of it.

Disk (storage). A device on which large amounts of information can be stored in the data base. Disk is synonymous with magnetic disk storage or magnetic disk memory.

Display. A CAD/CAM work station device for rapidly presenting a graphic image so that the designer can react to it, and make changes interactively in real time. Usually refers to a CRT.

DNC (direct numerical control). A system in which sets of NC machine instructions are connected to a computer to establish a direct interrelationship between the DNC command and the machine tool.

Dot-Matrix Plotter. A CAD peripheral device for generating graphic plots. Consists of a combination of wire nibs (styli) spaced 100 to 200 styli per inch, which place dots where needed to generate a drawing. Because of its high-speed, it is typically used in electronic design applications. Accuracy and resolution are not as great as with pen plotters. Also known as electrostatic plotter.

Drum Plotter. An electromechanical pen plotter that draws an image on paper or film mounted on a rotatable drum. In this CAD peripheral device a combination of plotting-head movement and drum rotation provides the motion.

Dynamic Menuing. This feature allows a particular function or command to be initiated by touching an electronic pen to the appropriate key word displayed in the status text area on the screen.

FMS (flexible manufacturing system). A group of automatic tools such as CNC machine tools that can randomly process a group of parts having different process sequences and process cycles. The system can adapt automatically to changes of part production mixes and levels of output.

File. A collection of related information in the system which may be accessed by a unique name. May be stored on a disk, tape, or other mass storage media.

Flatbed Plotter. A CAD/CAM peripheral device that draws an image on paper, glass, or film mounted on a flat table. The plotting head provides all the motion.

Font, Line. Repetitive pattern used in CAD to give a displayed line appearance characteristics that make it more easily distinguishable, e.g., a solid dashed, or dotted line. A line font can be applied to graphic images in order to provide meaning, either graphic (e.g., hidden lines) or functional (e.g., roads, tracks, wires, pipes, etc.). It can help a designer to identify and define specific graphic representations of entities which are view-dependent. For example, a line may be solid when drawn in the top view of an object, but when a line font is used, becomes dotted in the side view where it is not normally visible.

Font, Text. Sets of type faces of various styles and sizes. In CAD, fonts are used to create text for drawings, special characters such as Greek letters, and mathematical symbols.

Function Key. A specific square on a data tablet, or a key on a function key box, used by the designer to enter a particular command or other input. See also data tablet.

Graphic Tablet. A CAD/CAM input device which enables graphic and location instructions to be entered into the system using an electronic pen on the tablet. See also data tablet.

Grid. A network of uniformly spaced points or crosshatch optionally displayed on the CRT and used for exactly locating and digitizing a position, inputting components to assist in the creation of a design layout, or constructing precise angles. For example, the coordinate data supplied by digitizers is automatically calculated by the CPU from the closest grid point. The grid determines the minimum accuracy with which design entities are described or connected. In the mapping environment, a grid is used to describe the distribution network of utility resources.

Hard Copy. A copy on paper of an image displayed on the CRT, e.g., drawings, printed reports, plots, listings, or summaries. Most CAD/CAM systems can automatically generate hard copy through an on-line printer or plotter.

Hardware. The physical components, modules, and peripherals comprising a system, e.g. computer, disk, magnetic tape, CRT terminal(s), and plotter(s).

Hidden Lines. Line segments that would ordinarily be obscured from view in a 3D display of a solid object because they are behind other items in the display. On a CAD system with 3D capabilities, hidden lines can be displayed or removed, as the user specifies.

INV. (inventory)

Input (data). (1) The data supplied to a computer program for processing by the system. (2) The process of entering such data into the system.

Input Devices. A variety of devices (such as data tablets or keyboard devices) that allow the user to communicate with the CAD/CAM system, for example, to pick a function from many presented, to enter text and/or numerical data, to modify the picture shown on the CRT, or to construct the desired design.

Instruction Set. (1) All the commands to which a CAD/CAM computer will respond. (2) The repertoire of functions the computer can perform.

Intelligent Work Station/Terminal. A work station in a system which can perform certain data processing functions in a stand-alone mode, independent of another computer. Contains a built-in computer, usually a microprocessor or minicomputer, and dedicated memory. See also distributed processing.

Interactive. Denotes two-way communications between a CAD/CAM system or work station and its operators. An operator can modify or terminate a program and receive feedback from the system for guidance and verification.

Interactive Graphics System (IGS) or interactive computer graphics. A CAD/CAM system in which the work stations are used interactively for computer-aided design and/or drafting, as well as for CAM, all under full operator control, and possibly also for text-processing, generation of charts and graphs, or computer-aided engineering. The designer (operator) can intervene to enter data and direct the course of any program; immediate visual feedback is received via the CRT. Bilateral communication is provided between the system and the designer(s). Often used synonymously with CAD.

Jaggies. A CAD jargon term used to refer to straight or curved lines that appear to be jagged or saw-toothed on the CRT screen.

Layering. A method of logically organizing data in a CAD/CAM data base. Functionally different classes of data (e.g., various graphic/geometric entities) are segregated on separate layers, each of which can be displayed individually or in any desired combination. Layering helps the designer distinguish among different kinds of data in creating a complex product such as a multilayered PC board or IC.

Learning Curve. A concept that projects the expected improvement in operator productivity over a period of time. Usually applied in the first 1 to 1 1/2 years of a new CAD/CAM facility as part of a cost-justification study, or when new operators are introduced. An accepted tool of management for predicting manpower requirements and evaluating training programs.

Library Graphics (or parts library). A collection of standard, often-used symbols, components, shapes, or parts stored in the CAD data base as templates or building blocks to speed up future design work on the system. Generally an organization of files under a common library name.

Light Pen. A hand-held photosensitive CAD input device used on a refreshed CRT screen for identifying display elements, or for designating a location on the screen where an action is to take place.

Line Printer. A CAD/CAM peripheral device used for rapid printing of data.

MRP (manufacturing resource planning).

mrp (material requirement planning).

Magnetic Disk. A flat circular plate with a magnetic surface on which information can be stored by selective magnetization of portions of the flat surface. Commonly used for temporary working storage during computer-aided design. See also disk.

Magnetic Tape. A tape with a magnetic surface on which information can be stored by selective polarization of portions of the surface. Commonly used in CAD/CAM for off-line storage of completed design files and other archival material.

Mainframe (computer). A large central computer facility.

Mass Storage. Auxiliary large-capacity memory for storing large amounts of data readily accessible by the computer. Commonly a disk or magnetic tape.

Memory. Any form of data storage where information can be read and written. Standard memories include random access memory and read-only memory.

Megabyte. One million bytes of digital information.

Menu. A common CAD/CAM input device consisting of a checkerboard pattern of squares printed on a sheet of paper or plastic placed over a data tablet. These squares have been preprogrammed to represent a part of a command, a command, or a series of commands. Each square, when touched by an electronic pen, initiates the particular function or command indicated on that square. See also data tablet and dynamic menuing.

Microcomputer. A smaller, lower-cost equivalent of a full-scale minicomputer. Includes a microprocessor (CPU), memory, and necessary interface circuits. Consists of one or more ICs (chips) comprising a chip set.

Minicomputer. A general purpose, single processor computer of limited flexibility and memory performance.

Model, Geometric. A complete, geometrically accurate 3D or 2D representation of a shape, a part, a geographic area, a plant or any part of it, designed on a CAD system and stored in the data base. A mathematical or analytical model of a physical system used to determine the response of that system to a stimulus or load.

Modeling, Solid. A type of 3D modeling in which the solid characteristics of an object under design are built into the data base so that complex internal structures and external shapes can be realistically represented. This makes computer-aided design and analysis of solid objects easier, clearer, and more accurate than with wire-frame graphics.

Modem MODular-DEModulator. A device that converts digital signals to analog signals, and vice versa, for long-distance transmission over communications circuits such as telephone lines, dedicated wires, optical fiber, or microwave.

Mouse. A hand-held data entry device used to position a cursor on a data tablet. See cursor.

NC (numerical control). Prerecorded information providing instructions for the automatic computer control of machine tools, drafting machines and other operations.

Operating System. A structured set of software programs that control the operation of the computer and associated peripheral devices in a CAD/CAM system, as well as the execution of computer programs and dataflow to and from peripheral devices. May provide support for activities and programs such as scheduling, debugging, input/output control, accounting, editing, assembly, compilation, storage assignment, data mangement and diagnostics. An operating system may assign task priority levels, support a file system, provide drives for I/O (input/output) devices, support standard system commands or utilities for on-line programming, process commands, and support both networking and diagnostics.

Output. The end result of a particular CAD/CAM process or series of processes. The output of a CAD cycle can be artwork, hardcopy lists or reports. The output of a total design-to-manufacturing CAD/CAM system can also include numerical control tapes for manufacturing.

Pen Plotter. An electromechanical CAD output device that generates hard copy of displayed graphic data by means of a ballpoint pen or liquid ink. Used when a very accurate final drawing is required. Provides exceptional uniformity and density of lines, precise positional accuracy, as well as various user-selectable colours.

Peripheral (device). Any device, distinct from the basic system modules, that provides input to and/or output from the CPU. May include printers, keyboards, plotters, graphics display terminals, paper-tape reader/punches, analog-to-digital converters, disks, and tape drives.

Pixel. The smallest portion of a CRT screen that can be individually referenced. An individual dot on a display image. Typically, pixels are evenly spaced, horizontally and vertically, on the display.

Plotter. A CAD peripheral device used to output, for external use, the image stored in the data base. Generally makes large, accurate drawings of substantially better quality/resolution than what is displayed. Plotter types include: pen, drum, electrostatic, and flatbed.

Program. A precise sequential set of instructions that direct a computer to perform a particular task or action, or solve a problem. A complete program includes plans for the transcription of data, coding for the computer, and plans for the absorption of the results into the system. As a verb, it means to develop a program. See also computer program.

Puck. A hand-held, manually controlled input device which allows coordinate data to be digitized into the system from a drawing placed on the data tablet or digitizer surface. A puck has a transparent window containing crosshairs.

Random-Access Memory (RAM). A main memory read/write storage unit which provides the CAD/CAM operator direct access to the stored information.

Raster Display. A CAD work-station display in which the entire CRT surface is scanned at a constant refresh rate. The bright, flicker-free image can be selectively written and erased. Also called a digital TV display.

Raster Scan (video). Currently, the dominant technology in CAD graphic displays. Similar to conventional television, it involves a line-by-line sweep across the entire CRT surface to generate the image. Raster scan features include: good brightness, accuracy, selective erase, dynamic motion capabilities, and the opportunity for unlimited colour. The device can display a large amount of information without flicker, although resolution is not as good as with storage-tube displays.

Read-Only Memory (ROM). A memory which cannot be modified or reprogrammed. Typically used for control and execute programs.

Refresh (or vector refresh). A CAD display technology that involves frequent redrawing of an image displayed on the CRT to keep it bright, crisp, and clear. Refresh permits a high degree of movement in the displayed image as well as high resolution. Selective erase or editing is possible at any time without erasing and repainting the entire image. Although substantial amounts of high-speed memory are required, large, complex images may still flicker.

Resolution. The smallest spacing between two display elements which will allow the elements to be distinguished visually on the CRT. The ability to define very minute detail. For example, the resolution of Computervision's IC design system is one part in 33.5 million. As applied to an electrostatic plotter, resolution means the number of dots per square inch.

Response Time. The elapsed time from initiation of an operation at a workstation to the receipt of the results at that work station. Includes transmission of data to the CPU, processing, file access, and transmission of results back to the initiating work station.

Software. The collection of executable computer programs including application programs, operating systems, and languages.

Storage. The physical repository of all information relating to products designed on a CAD/CAM system. It is typically in the form of a magnetic tape or disk. Also called memory.

System. An arrangement of CAD/CAM data processing, memory, display and plotting modules which when coupled with the appropriate software, is used to achieve specific objectives. The term CAD/CAM system implies both hardware and software. See also operating system (a purely software term).

Tablet. An input device on which a designer can digitize coordinate data or enter commands into a CAD/CAM system by means of an electronic pen. See also data tablet.

Text File. A file stored in the system in text format which can be printed and edited on-line as required.

Track Ball. A CAD graphics input device consisting of a ball recessed into a surface. The designer can rotate it in any direction to control the position of the cursor used for entering coordinate data into the system.

Turnkey. A CAD/CAM system for which the supplier/vendor assumes total responsibility for building, installing, and testing both hardware and software, and the training of user personnel. Also loosely, a system which comes equipped with all the hardware and software required to do a specific application or applications. Usually implies a commitment by the vendor to make the system work, and to provide preventive and remedial maintenance of both hardware and software. Sometimes used interchangeably with standalone, although standalone applies more to system architecture than to terms of purchase.

View Port. A user-selected, rectangular view of a part, assembly, etc., which presents the contents of a window on the CRT. See window.

Window. A temporary, usually rectangular, bounded area on the CRT which is user-specified to include particular entities for modifications, editing, or deletion.

Wire-Frame Graphics. A computer-aided design technique for displaying a three-dimensional object on the CRT screen as a series of lines outlining its surface.

Work Station. The work area and equipment used for CAD/CAM operations. It is where the designer interacts (communicates) with the computer. Frequently it consists of a CRT display and an input device as well as, in some cases, a digitizer and a hard-copy device. In a distributed processing system, a work station would have local processing and mass storage capabilities. Also called a terminal or design terminal.

Zoom. A CAD capability that proportionately enlarges or reduces a figure displayed on a CRT screen.

APPENDIX 3 CAD/CAM CENTRES

CAD/CAM CENTRES IN CANADA

The following industrially oriented centres are listed in geographic sequence from west to east, followed by some national facilities. Other capabilities then input, exist and additional centres are being planned in some instances. The centres listed, or the relevant provincial research council, are often aware of such activities and are a good point of contact in such cases.

Alberta Microelectronic Centre

A non-profit company, established to help Alberta industry learn about, and profit from, new technology. The centre assists companies with feasibility studies on productivity improvement, including CAD/CAM and robotics. Facilities include a Computervision CAD system with eight work stations.

Contact: Alberta Microelectronic Centre
Room 544, Electrical Engineering Building
The University of Alberta
Edmonton, Alberta T6G 2G7
Telephone (403) 432-3914

Saskatchewan CAD/CAM Robotics Centre

The Saskatchewan Research Council (SRC) has made a commitment to Saskatchewan industry to establish the use of CAD/CAM in manufacturing plants in the province. The centre, will focus on the improvement of productivity, technical competence and the competitive position of the Saskatchewan industrial sector.

Contact: Mr. G. Pierce, P.Eng.
Saskatchewan Research Council
30 Campus Drive
Saskatoon, Saskatchewan S7N 0X1
Telephone (306) 664-5413

Computer Aided Engineering Facility

The Computer Aided Engineering Facility at the Manitoba Research Council's Industrial Technology Centre in Winnipeg, jointly funded by federal and provincial governments was established to enhance the range of services and equipment available in the area of computer aided design and computer aided manufacturing (CAD/CAM) in Manitoba.

The facility, in addition to serving Industrial Technology Centre clients, interfaces with Manitoba's major educational institutions to encourage the training of technologists, engineers and designers in the use of computer aided engineering.

Further information can be obtained from:

Computer Aided Engineering Facility
Industrial Technology Centre
1329 Niakwa Road
Winnipeg, Manitoba R2J 3T4
Telephone (204) 994-6000

The Canadian Institute of Metalworking (CIM)

The Canadian Institute of Metalworking (CIM) was originally located on the campus of McMaster University as a non-profit corporation. It has more than eleven years of industrial experience in numerical control machine tool application and several years in CAD. In 1981, the Institute reinforced its capabilities with the acquisition of a CALMA interactive graphics system for computer aided design, drafting and manufacturing.

Contact: Canadian Institute of Metalworking
1276 Sandhill Drive
P.O. Box 7317
Ancaster, Ontario L9G 3N6
Telephone (416) 648-5011

McMaster University Flexible Manufacturing Centre

As a result of a grant approved under the Federal Government Centres of Specialization Fund, McMaster University announced in 1984 that the \$500 000 granted will be used to establish a "Centre for Flexible Manufacturing Research and Development" at the University.

The planned activities of the centre will be multi-disciplinary, combining mechanical, electrical and computer engineering and management expertise. The centre will serve also as a regional resource for the industrial community and will complement other programs sponsored by federal and provincial governments and research councils.

Contact: Dr. Hoda A. ElMaraghy
Director, Center for FMS R&D
Dept. of Mechanical Engineering
McMaster University
Hamilton, Ontario L8S 4L7

The Ontario Centre for CAD/CAM

The Ontario Centre for CAD/CAM in Cambridge and the Ontario Centre for Robotics in Peterborough, jointly constitute the Ontario Centre for Advanced Manufacturing (OCAM).

Contact: Ontario CAD/CAM Centre
400 Collier-MacMillan Drive
Cambridge, Ontario N1R 7H7
Telephone (519) 622-3100

Ontario Centre for Robotics

The Ontario Centre for Robotics in Peterborough, Ontario, forms the second half of the Ontario Centre for Advanced Manufacturing. The goals of the Robotics Centre are:

- to accelerate the utilization of robotics technology by Ontario industry, and
- to promote the growth of supportive robotics industries in Ontario.

Contact: Ontario Robotics Centre
743 Monaghan Road
Peterborough, Ontario K8J 5K2
Telephone (705) 876-1611

The Ontario Centre for Microelectronics

The Ontario Centre for Microelectronics, in addition to its other capabilities, has an intensive set of CAD tools for the design of integrated circuits and customized silicon chips.

Contact: Ontario Centre for Microelectronics
1150 Morrison Drive, 4th Floor
Ottawa, Ontario K2H 9B8
Telephone (613) 596-6685

Carleton University "CASCADE" Centre

As a university response to re-structuring and adapting to the change precipitated by CAD/CAM technology, Carleton University in Ottawa officially opened the Centre for Advanced Studies in Computer Aided Design and Engineering (CASCADE), on October 15, 1984.

The Centre is dedicated to the advancement of Computer Integrated Design and Manufacturing (CIDM).

Contact: CASCADE,
Centre for Advanced Studies in Computer Aided Design and
Engineering
Carleton University
Ottawa, Ontario Canada
K1S 5B6

Concordia University - Centre for Building Studies

The Concordia University Centre for Building Studies has expertise in CAD as applied to architecture and building design.

Contact: Dr. P. Fazio
Centre for Building Studies
Concordia University
1455 de Maisonneuve Blvd., West
Montreal, Quebec H3G 1M8

Concordia University - Computer Aided Engineering

A booklet is available describing Research and Academic Activities in Computer Aided Engineering (CAE) in the Department of Mechanical Engineering, Concordia University.

Contact: Dr. S. Sankar, Associate Professor
Department of Mechanical Engineering
Sir George Williams Campus
1455 Maisonneuve Blvd. West
Montreal, Quebec H3G 1M8

New Brunswick Manufacturing Technology Centre

The New Brunswick Manufacturing Technology Centre was established in 1983 at six institutional locations to provide critical skill training and technical advisory service to industry on CAD/CAM.

Department of Commerce and Development

Mr. W.C. McGregor, Director, Manufacturing Services Division
Mr. B. Teece, Manager, Manufacturing Technology Centres and Software Development
Mr. Otis Phinney, Industry Services Officer, CAD/CAM
P.O. Box 600
Fredericton, New Brunswick E3B 5H1
Telephone (506) 453-2790

New Brunswick Research and Productivity Council

Mr. Neville Coelho, CAD/CAM Centre Manager
P.O. Box 6000
Fredericton, New Brunswick E3B 5H1
Telephone (506) 455-8994

The University of New Brunswick

Dr. D.J. Bonham, Chairman, Mechanical Engineering
Ms Evelyn Richards, Project Director
P.O. Box 4400
Fredericton, New Brunswick E3B 5A3

Universite de Moncton

M. Jean Rene Longval, CAD/CAM Centre Manager
Engineering Department
Moncton, New Brunswick E1A 3E9
Telephone (506) 858-4309
(506) 858-4562

N.B.C.C., Campus de Bathurst

Ms Jocelyne Vienneau, CAD/CAM Centre Manager
725 College
C.P. 1
Bathurst, New Brunswick E2A 3Z2
Telephone (506) 548-4591

N.B.C.C., Moncton Campus

Mr. John Hanusiak, CAD/CAM Centre Manager
1234 Mountain Road
P.O. Box 2100, Station "A"
Moncton, New Brunswick E1C 8H9
Telephone (506) 384-4473
(506) 384-4306

N.B.C.C., Saint John Campus

Mr. Syd Brittain, CAD/CAM Centre Manager
Grandview Avenue
P.O. Box 2270, Station "C"
Saint John, New Brunswick E2L 3V1
Telephone (506) 696-1860
(506) 696-5452

Computer Aided Design Centre - Nova Scotia

A computer aided design centre was established in 1983 at the Technical University of Nova Scotia. The centre, shares the computer aided manufacturing resources located at the Nova Scotia Institute of Technology.

Contact: Dr. A.A. Mufti, Director
Computer Aided Design Centre
Technical University of Nova Scotia
P.O. Box 1000
Halifax, Nova Scotia B3J 2X4
Telephone (902) 429-8300, ext. 350

APPENDIX 4 LIST OF PUBLICATIONS

Appendix 4 List of Publications (cont'd)

Computer-Aided Design Report (newsletter)
711 Van Nuys Street
San Diego, California 92109

Computer Graphics (Journal of the ACM Special
Interest Group on Computer Graphics) (monthly)
Association for Computing Machinery
1133 Avenue of the Americas
New York, New York 10036

The Computer Graphics Software News (newsletter)
5857 South Gessner, Suite 401
Houston, Texas 77036

Computer Graphics World (monthly)
Pennwell Publishing Company
1714 Stockton Street
San Francisco, California 94133

Computers and Graphics
Pergamon Press, Inc.
Maxwell House, Fairview Park
Elmsford, New York 10523

Displays Technology and Applications
ICP Science and Technology Press
P.O. Box 63
Westbury House, Bury Street
Guildford, Surrey, GU2 5BH, England

Engineering Computer Applications Newsletter
Engineering Computer Applications, Inc.
5 Denver Tech. Center
P.O. Box 3109
Englewood, Colorado 80111

Finite Element News (newsletter)
HG Engineering Ltd.
260 Lesmill Road
Don Mills, Ontario M3B 2T5, Canada

Appendix 4 List of Publications (cont'd)

IEEE Computer Graphics and Applications (monthly)
IEEE Computer Society
10662 Los Vaqueros Circle
Los Alamitos, California 90720

NCGA Computer Graphics News
Sherago Associates Inc.
1515 Broadway
New York, New York 10036

Proceedings of the SID (quarterly)
Society for Information Displays
654 North Sepulveda Boulevard
Los Angeles, California 90049

SID Journal (quarterly)
Society for Information Displays
654 North Sepulveda Boulevard
Los Angeles, California 90049

The S. Klein Newsletter on Computer Graphics
730 Boston Post Road
P.O. Box 89
Sudbury, Massachusetts 01776

APPENDIX 5 LIST OF VENDORS

Appendix 5 List of Vendors

idors:

ion Canada Inc.
Avenue N.E.
berta T2E 7E1

Ltd.
Street
lberta T5J 3P4

Ltd.
laza
Avenue S.W. Ste. 600
lberta T2P 3N5

SYSTEMS LTD.
h Street, N.E.
lberta T2E 7J2

PANY
, 1 Young Street
ntario M5E 1E5

Douglas Canada Ltd.
6013
Ontario L5P 1B7

Missauga Road
ga, Ontario L5N 2W3

Data
Minnesota Court
uga, Ontario L5N 1K7

1
5 - 6120 - 2nd Street, S.E.
Alberta T2H 2L8

APPENDIX 6 LIST OF REFERENCES

The CAD/CAM, Edited by Carl Machoven and Robert E. Blauth,
Computervision Corporation, Bedford, Mass.

Glossary of Terms, Computervision Corporation, Bedford, Mass.
(with permission)

National Computer Graphics Association,
Computer Graphics'84, conference proceedings

Artificial Intelligence, John F. Gilmore,
Georgia Institute of Technology

CIM, Today and Tomorrow - An Evolution, David C. Scott,
John Deere, Manufacturing and Engineering

Merging CAD/CAM and Manufacturing Systems, Michael P. Carroll,
Sperry Corp, Computer Systems Division

CAD/CAM Workstation Trends, Edward L. Busick
Computer Graphics World, April 1984

Trends in a Fiercely Competitive Marketplace, Marlene Brown
Computer Graphics World, April 1984

Buying CAD/CAM Graphics, Charles M. Foundyller
American Machinist, July 1981

Making a Start in CAD
ENGINEERING, MATERIALS AND DESIGN 1982
March - The Hardware
April - The Software
May - Matching System of Application
June - Organizing the Office Routine
July - Linking With Production
August - Getting Started

Computer-Aided Design - Significant
CAD power is coming for desktop microcomputers - Rik Jadrnicek
Bute Publications Inc.

Cad Increases Effectiveness - Ken Mark
Canadian Building, March 1984

Choosing a Turnkey CAD System - Eric Teicholz
DATAMATION

Computer Aided Design Report, July 1983

Computer Aided Design - Systems
Evaluation and Selection, Richard F. Barrett
Tappi Press, September 1980

Automated Factories: The ultimate union of CAD and CAM, John K. Krouse,
Machine Design, November 26, 1981

Flexible Manufacturing - A Strategy for Winning, Donald H. Hegland,
Production Engineering, September 1982

A Workshop on Artificial Intelligence,
Science Council of Canada, Proceedings, January 1983

A Framework for Integrated Assembly Systems. Humans, Automation & Robots,
Jila Kami, Colin L. Moodie and Gaviel Salvendy, School of Industrial
Engineering, Purdue University West Lafayette, Indiana, 47907, USA.

Japan takes early lead in Robotics
ENR/July 21, 1983

How to Define and Plan a System for Integrated Closed Loop Manufacturing
Central, Edward J. Anstead,
IE, September 1983

Keys to Successful Computerization of the Material Management System,
Robert M. Burlingame, IE, April 1982