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TrussCAD a three-dimensional computer aided design program to generate roof and floor truss profiles and placement.

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TRUSSCAD: A THREE-DIMENSIONAL COMPUTER AIDED DESIGN PROGRAM TO GENERATE ROOF AND FLOOR TRUSS PROFILES AND PLACEMENT

by

© THOMAS L. DEBEVEC

A thesis submitted to the Faculty of Graduate Studies and Research through the Department of Civil and Environmental Engineering in Partial Fulfillment of the requirements for the Degree of Master of Applied Science at the University of Windsor

Windsor, Ontario, Canada

1988
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ABSTRACT

The objective of this project was to develop a computer program, TrussCAD, on a personal computer that can be used by architects, design engineers and truss fabricators to generate roof and floor truss profiles and layout drawings. By computerizing these processes a time saving will be achieved during the revision stages of roof design. Plots produced by the program can be used as truss layout plans. These plans specify the placement of each truss in a building and are used by truss installers. The data generated from this program could be used as the input data for existing truss analysis programs. The program was written in Fortran with the three-dimensional graphics routines written in Assembler. The program can determine the truss placement and truss profiles for the hip, gable and flat roof styles. The trusses can have triangular, flat, hip, stub, and dual pitch profiles. The program uses three-dimensional graphics which allows truss profiles or any view of a building to be displayed. The program is interactive, user-friendly and menu driven.
To my parents
ACKNOWLEDGMENTS

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NOMENCLATURE

$A_1, A_2$  = horizontal location of truss peak
$\text{b}$  = y-intercept
$\text{Cant}_2, \text{Cant}_4$  = cantilever values of a truss
$\text{Heel}_2, \text{Heel}_4$  = heel height values of a truss
$idiff$  = difference between center of the computer display screen and drawing window
$(ix_{cen}, iy_{cen})$  = screen coordinates of the center of the computer display screen
$iy'_{cen}$  = y coordinate of the center of the drawing window
$(ixs_{new}, iys_{new})$  = screen coordinates calculated by zoom subroutine
$(ixs_{old}, iys_{old})$  = screen coordinates before being operated on by the zoom subroutine
$[M]$  = master modeling matrix
$m$  = slope of a line in the X-Y plane
$\text{Over}_2, \text{Over}_4$  = overhang values of a truss
$\text{Pit}_2, \text{Pit}_4$  = pitch values of a truss
$r$  = the linear distance from a point to the coordinate origin
$rscale$  = scale factor used in zooming
$\text{Setback}$  = setback value
$\text{Span}_1$  = span of a truss
$(S_x, S_y, S_z)$  = X, Y and Z scaling factors
$[T]$  = transformation matrix
$(T_x, T_y, T_z)$  = X, Y and Z translations
$(x', y', z')$  = transformed coordinates of a point, $(x, y, z)$
$ix$
\[(X_1, Y_1)\] = start point of a line
\[(X_2, Y_2)\] = end point of a line
\[(x_h, y_h, z_h, k)\] = homogeneous coordinate representation of point, \((x, y, z)\)
\[(x_p, y_p, z_p)\] = projected coordinates of a point, \((x, y, z)\)
\[z_l\] = vertical distance of truss peak above the top plates
\[z_e\] = elevation of eaves line
\[\theta\] = rotation angle about a given axis
\[\phi\] = initial rotation angle about a given axis
Chapter I

INTRODUCTION

1.1 General

With the cost of microcomputers decreasing and computing power increasing, their use in the field of engineering is growing steadily. Engineering firms are performing more of their design work on personal computers running Computer Aided Design and Drafting (CADD) software. The primary advantages are in time savings during the modification phase of design and in ease of use. The geometry of the design can be viewed from all angles allowing the designer to see the part before it is actually built and the resulting geometry can be the input for analysis programs.

Specifically in the truss industry there is a need and demand for CADD programs that generate truss profiles and layout plans. A layout plan shows the location of each truss on the plan view of the building. This is important during the construction phase of a building to ensure trusses are properly positioned. The truss profiles, which
describe the fundamental geometry of a truss, are required as the input for existing truss analysis programs. The analysis programs determine forces within the truss members. A program that achieves these goals would free engineers and technicians from tedious and time consuming hand calculations allowing them to use their time for more creative endeavors.

In preparation for this project the author was employed by a truss designer/truss plate manufacturer during the Summer of 1986. Here the author became familiar with the workings of the truss industry by designing trusses, calculating truss layout plans and quantity takeoffs. The designing of the trusses was performed with the aid of a truss analysis computer program. A truss manufacturer provided the truss designer with the loading, top and bottom chord profile, overhangs, cantilevers, heel heights, and support locations of a truss. (Truss terms are defined in Appendix A. This appendix should be referred to throughout this report for an explanation of unfamiliar terms.) These values were manually entered into the analysis program. The size and grade of lumber were selected along with the web configurations. The analysis was carried out and the results were checked to ensure the stresses in the members did not exceed those specified in the Canadian Standards Association's "Engineering Design in Wood" [1]. Also the joints were checked to ensure the metal connector plates
were adequate to carry the loads. A serviceability check of deflections was also performed. If the truss design proved to be either too conservative or unsafe the appropriate parameters were changed and the analysis performed again. This was repeated until a feasible design was found. At a truss fabricator the author calculated truss layout plans and quantity takeoffs for residential buildings. The author was also involved in the manufacturing of trusses. Performing these duties provided the information necessary to calculate the location of ridge and eaves lines. This is very important in regards to truss layout and profile calculations. This experience put the author in an excellent position to tailor a computer program to the needs of the truss industry.

1.2 Truss Industry Background

The workings of the truss industry must be examined in order to gain an understanding of the communication and interaction of all parties involved in the planning, design and construction of a roof truss system. The parties involved in this process are the architect/consulting engineer, truss fabricator and truss designer/truss plate supplier. This complex process has many tedious calculations and numerous communication links that can lead to errors in truss geometry and truss layout. The end result could be
incorrect calculation of truss profiles. If this occurred
the desired appearance of the roof would be changed. The
alternative in this situation is to perform on-site
modification of the trusses or manufacture new ones.
This is time consuming and increases the cost of a given
structure.

The parties' responsibilities, duties and relationships
are stated below in the different stages of a truss design.

Stage 1. Architect/consulting engineer

- provide precise drawings of the building ensuring
  that cross-sections and elevations are matched
  exactly.
- determine correct dimensioning of elements.
- forward the building plans to the truss
  fabricators.

Stage 2. Truss fabricator

- must have the expertise to perform truss takeoffs
  from the architectural drawings and check for the
  match of cross-sections. Makes note of elevation
  differences since these will effect the snow load
  on the trusses.
- must have the ability to communicate this
  information to the truss designer/truss plate
  manufacturer. The common communication channels
  are mail, fax, courier service or sending the
  architectural plans directly to the truss
  designer/truss plate manufacturer to have the
  takeoffs done.

Stage 3. Truss designer/truss plate manufacturer

- must correctly record the requirements received
  from the truss fabricator.
- must have the trained personnel to design and
  execute the structural analysis program.
- the final designs are stamped by a professional
  engineer and submitted to the truss fabricator.
Stage 4. Truss fabricator

-examines truss designs and calculates how each truss member should be cut to ensure proper fit. This is done with the aid of computer software supplied by the truss designer or with the use of a calculator that has trigonometric capabilities. The other method is to match and cut on a jig. -must draw a truss layout plan indicating the location of each truss on the building.

This is not the only manner of interaction but is one of the most common. Other variations are possible. The process is shown schematically in Figure 1.1. If all the pertinent information about the roof is entered into a computer program and stored at an early stage of the roof development the chances of calculation errors and communication errors will be greatly reduced. Also with the aid of three-dimensional graphics the proposed roof could be displayed to give the designer a view of how the roof will appear before it is built. In the current process there is a need for duplicate input which could be eliminated.

A logical location to enter the data would be at Stage 1 or 2 (see page 4). This would enable the data generated and stored by a program to be the input data for other programs. For instance, once the truss profiles are generated this would be the input data for a truss analysis program and once the trusses are designed the results would be the input data for a truss member cutting program.
1.3 **Objective**

The objective is to develop a computer program that can be used by architects, design engineers, and truss fabricators to generate truss profiles and layout. It is to be developed on a personal computer since most companies in the truss industry have access to one. The characteristics of the program should be:

a) Three-dimensional graphic capabilities,

b) Interactive and user friendly,

c) Flexible in terms of types of buildings the program can handle,

d) Simple input of data,

e) Editing capabilities,

f) Viewing of truss layout plans and truss profiles,

g) Prompts and error messages,

h) Easily linked to existing truss industry related programs, and

i) File management within the program.

It is understood that there are commercially available programs that could conceivably be tailored for this purpose but they are too expensive and too general in nature to be used effectively. In addition, the need to link the results of the program to existing truss industry related programs would be difficult to satisfy.
1.4 Constraints

The following are the constraints of the buildings that the program can deal with:

a) The roof style is either hip, gable or flat,

b) The trusses generated have a triangular or flat profile,

c) There can be one or two interior bearings for each truss,

d) The exterior load bearing walls meet at ninety degree angles,

e) The exterior load bearing walls run parallel to a X or Y axis, and

f) The building's exterior walls can be modeled as a series of right rectangular prisms.
Chapter II

PROGRAM DESIGN AND DEVELOPMENT

2.1 Menu Design

There are two basic methods of entering commands into a program. One is to display a menu of the command options on the screen with the unique key press indicated to select each option. The other is not to display the list of commands but to have keywords typed in on a command line to select an option. The advantage of the second method is that there is more space on the screen for other program functions like a larger graphics area. The disadvantage is that it demands that the operator memorize the options available within the program and the keywords to select the options. The first method does not burden the operator with the need for memorization of commands allowing complete concentration on the engineering problem. Also a menu of command options is an invaluable tool to help the first time and infrequent user operate the program. For these reasons it was decided to use menus of command options throughout TrussCad.
With the decision to utilize menus having been made, the positioning of them on the display screen had to be determined. The locations considered were a column along the side of the display with each option occupying a single line or a row at the top of the screen with the options separated by spaces. The column approach allows the operator to identify the individual options more easily and quickly because the options are spaced at equal intervals. In the row approach the option names are generally unequal in length making it more difficult to quickly view the options available. The choice between a row or a column approach is not the only consideration when positioning the menu. There is a need to provide a prompt line that gives information on which option to select or what data to enter. If the prompt line is placed close to the menu both can be read by looking at the same area on the screen. A menu in a row format makes this possible. A menu row was, therefore, placed at the top of the display screen with the prompt line directly below it. An example of this is shown in Figure 2.1. It is the Main Menu of TrussCad in which one character in each menu option is highlighted in red with a prompt below. Pressing the appropriate highlighted character selects the desired option. The rest of the screen is used to display the building and is called the drawing window.
2.2 Data Entry

To determine what data is necessary to generate the truss profiles and layout the construction of a building must be reviewed. In Figure 2.2 the framing of a typical one-storey building is shown. A footing is placed below the frost line on suitable load bearing soil. The foundation walls start at the footing and end above the finished grade line. The footing is usually made of concrete that is poured on site with the foundation walls made of concrete block or poured-in-place concrete. On top of the foundation walls a sill plate is fastened followed by the floor joists, the rough floor and then the bottom plate. The bottom plate provides material into which the wall studs can be nailed. The wall studs are generally 2 x 4 or 2 x 6 lumber. A top plate is nailed to the top of the wall studs. Roof trusses and roof framing are placed next with the top plates as supports. Plywood sheathing is nailed to the roof trusses to form the roof surfaces. The limits of a roof surface are defined by the eaves and ridge lines. From the viewpoint of truss profile generation and layout, the data defining top plate locations and eaves and ridge lines are most important. The top plates define the bottom chord profile and support locations. The eaves and ridge lines define the lower and upper limits of the top chord. The truss spacing, span direction and setback define the truss layout. In
summary, the data necessary for truss profile generation and layout are the location of top plates, eaves and ridge lines, spacing, span direction and setback.

2.2.1 Top Plate Entry

It was decided, in order to give the program operator the feeling of actually constructing the building to enter not only the location of top plates in a plan view but also the height of walls. This will reduce errors by allowing different views of the building to be produced permitting the operator to see how the roofs intersect. The manner in which they would be entered was investigated next. Upon viewing building floor plans and existing buildings it was noted that many walls intersect at ninety degree angles. Also many buildings can be broken down into a series of right rectangular prisms. (For simplicity, the right rectangular prisms that make up a building will be termed "cubes" throughout the thesis.) This is shown in Figure 2.3, where a moderately complex building can be broken down into three cubes. Another possibility is to view the building as having ten separate walls. If the building is broken down into cubes and stored as such by the program there is an association among walls which makes the entry of truss data easier. This is illustrated in the following example. The roof data for the area ABCD shown in Figure 2.3 is to be entered. In the first case the walls are
entered as a series of cubes. By indicating Cube 2, as the cube that the subsequent roof data pertains to, the support location for the trusses can only be either pair of opposing walls (walls 4 and 9 or walls 5 and 3). Entering the truss span direction as either in the X or Y direction indicates which pair of walls are the supports. The setback values are measured from the other pair of walls. For this method there are only two pieces of information to enter: the cube to frame and the truss span direction. If each wall is entered individually any pair of walls can be supports for a truss so the two support walls and the walls that the setbacks are measured from would have to be entered explicitly. In this method there are four pieces of information to enter: the first support wall, the second support wall and the two walls from which setbacks are to be measured. Therefore the method of defining a series of cubes for top plate entry was chosen. The characteristics of cubes used are vertical sides and horizontal tops and bases. The top of the cubes represent the top plates and the bottom of the cubes represent the top of the foundation walls (or any other convenient horizontal reference plane). The length and width of the cubes are measured in the X and Y coordinate directions and the height or elevation above the reference plane in the Z direction. In Figure 2.4 a cube is shown in which the eight vertices have been labeled. The base of a cube is taken to be at an elevation of zero. Since the sides are vertical, the X, Y and Z coordinates of
the vertices defining the top of cube are the only data
needed to define the cube. The bottom vertices \(Z=0\) can
easily be determined when needed. This approach decreases
the amount of data that must be entered and stored in the
computer.

The two methods investigated for entering cube vertex
coordinates were using the keyboard and using a mouse. In
both cases a data area was displayed on the screen in the
upper part of the drawing window. The data area was divided
into cells. Three cells existed for each of the four top
vertices. This data area is termed the Support Data Entry
Area and is shown in Figure 2.5. Imperial units are used
throughout the program since they are still widely used in
the construction industry. The data area displays the \(X\), \(Y\)
and \(Z\) coordinates of the four top vertices on a cube. The
coordinates are recorded to a resolution of one-sixteenth of
an inch.

The method of input using the mouse will be discussed
first. Using this method there were three distinct steps in
entering cube data. They were: a) establishing one of the
bottom vertices, b) specifying the other three bottom
vertices, and c) specifying the elevation of the cube.
Programming was put in place to monitor the movement of the
mouse. The cube input started by setting one of the bottom
vertices of the cube in the \(X-Y\) plane. This was done by
moving the mouse which caused the coordinate location of the
first vertex in the data area to be updated and a cursor to
move to this location on the drawing window. The "feet" portion was entered first and then key presses were necessary to enter the inches and sixteenth of an inch. Another key press set the first vertex. Further movement of the mouse caused both the X and Y coordinate values for the second, third and fourth vertices to be updated and the cube bottom to be displayed on the drawing window. A key press set the bottom. Mouse movements then caused the Z coordinate of all vertices to be changed. A final key press set the cube and allowed the entry of the next cube. This process was repeated for all cubes. A problem was encountered with this method when the X and Y coordinates of the vertices were entered. If the X value of a vertex was correct it was difficult to hold this while changing the Y value. The alternate method of using the keyboard proved to be simpler and faster. The arrow keys were used to highlight a cell in the data area and the numeric keys used to enter the coordinates of the top vertices. The "feet" are entered first, and pressing the return key enables entry of the "inches" then the "sixteenth of an inch". As the data was entered the cube is displayed on the drawing window. The keyboard method was found to be quickest and was adopted as the method for top plate input.
2.2.2 Roof Data Entry

The roof data should allow for the determination of the roof ridge and eaves lines, truss layout and truss profiles. To illustrate the data necessary to calculate the eaves and ridge lines, consider Figures 2.6 and 2.7 which show a section of a typical roof. It can be seen that the truss overhang, cantilever, heel height and pitch are the important features to define the roof lines. The truss features that affect the elevation of an eaves line \((Z_e)\) are the heel height, top chord pitch, and overhang. The equation of \(Z_e\), which is developed in Appendix B, is given by:

\[
Z_e = \frac{Pit4 \times Over4}{12} - Heel4
\]  

(2.1)

The horizontal location of the eaves lines are governed by the overhang and cantilever. The ridge line marks the upper limit of the truss top chord. The location of the ridge line is calculated by using the pitch, heel height, overhang and cantilever of opposing cube sides. The elevation of the ridge line \((Z1)\) and the horizontal placement \((A1)\) are given by the following equations. They are developed in Appendix B.

\[
Z1 = \frac{Pit4 \times (Span1 - Cant4 + Cant2 - A1) + Heel4}{12}
\]  

(2.2)

\[
A1 = \frac{Pit4 \times Span1 + Pit4 \times (Cant4+Cant2) + 12 \times (Heel4-Heel2)}{(Pit2 + Pit4)}
\]  

(2.3)
The importance of the pitch is not only to define the top chord profile but it also effects the wind and snow loads on the roof. The loads a roof is subjected to are used during the design stage and effect the lumber size and web configuration of the trusses.

Truss spacing, setback and span direction are used to position the trusses on the top plates. The truss layout also effects the truss profiles. In Figure 2.8, Truss 1 has a profile with part of the top chord flattened since it is positioned between the end wall and the upper ridge line. It is part of the step-down hip system. The profile is shown in Figure 2.9. To find the break point locations (A1, A2 and Z1) of the top chord on Truss 1, Section B-B from Figure 2.8 must be viewed. This section is shown in Figure 2.10. From Section B-B the height (Z1) of the break points can be calculated permitting their horizontal location to be established. The equations for Z1, A1, and A2 are listed below and are developed in Appendix B.

\[ Z1 = \frac{\text{Pit1} \times (\text{Setback} + \text{Cant1})}{12} \]  
\[ A1 = \frac{12}{\text{Pit4}} \times (Z1 - \text{Heel4}) \]  
\[ A2 = \frac{12}{\text{Pit2}} \times (Z1 - \text{Heel2}) \]

Truss 4 has a triangular profile since it is positioned at the beginning of the upper ridge line. This is not the only way to frame a hip end but is one of the most common.

Another system of framing is the California Hip System shown
in Figure 2.11. In this system all hip trusses use the same web configuration and chord size with the extended top chords and end jacks forming the full hip. The Step-Down Hip System is used in this project to frame the hip ends.

In summary, the data necessary to totally define roof features are:

a. Truss spacing,

b. Truss setback,

c. Truss span direction,

d. Top chord pitch,

e. Heel height,

f. Overhang, and

g. Cantilever.

The manner in which this data is to be entered was the next consideration. Since the top plates were entered by cubes it would be appropriate to enter the roof data cube by cube. Hence, the first required action is to identify the cube for which the data is to be applied. One method is to label each cube and have the operator type in the label of the desired cube. When the building is made of many cubes the display may become confusing when using this method. Another method is to highlight one cube at a time and have one key press to highlight the next cube and one to select the highlighted cube for roof input. This approach was taken because it leaves the display free from cube labels. The Next_cube option in Figure 2.12 is used to highlight a cube and the return key selects it.
The truss span direction could be entered by typing "X" or "Y". But a clearer method is to display an arrow on the cube representing the span direction. A key press would toggle between the two directions and another key press would choose the direction shown on the screen. With this method the operator can see the truss direction and does not have to remember the orientation of the axis. This is the approach taken in the program and is shown in Figure 2.13. The up arrow key is pressed to change the span direction and pressing the return key selects the span direction.

The pitch, heel height, overhang and cantilever for each side of a cube is entered in the Roof Data Entry Area. It is similar in appearance to the Support Data Entry Area. The manner in which data is entered and movement is achieved within the area are the same. A typical data entry screen is shown in Figure 2.14. The values for the four sides of the cube are entered using the numeric keys. Movement in the data area is through the arrow keys. The initial values for this data are zeros. The setback values and truss spacing values are not explicitly requested by prompting. Instead, there are menu options to change these values. Usually their values are the same for the entire building and the menu option approach saves time over the explicit prompt method. The values for the spacing and setback are displayed on the top line of the display screen. When all roof data for a particular cube has been entered, the Next option is selected from the menu shown in Figure 2.14 to
permit roof data entry for another cube. The menu from Figure 2.12 is displayed again and the same process is repeated for all cubes. When all roof data has been entered there is sufficient information to generate truss layout and truss profiles. The intersection lines for roofs over adjoining cubes can also be determined at this time. All these calculations are performed by the Combine option on the menu shown in Figure 2.12. In addition, this option identifies or groups trusses with identical profiles by assigning them a unique group letter.

The process of determining adjoining cubes is discussed below with the aid of the L-shape building shown in Figure 2.15. The points A, B and C are the intersections of the eaves and ridge lines of Cube 2 with the roof surfaces of Cube 1. Two cubes adjoin if there is a pair of common sides. If two cube bottoms have the same equation and one lies within the other the two cubes are adjoined. Only the X-Y plane equations are compared because the cube bottoms are horizontal. The three properties of the cube bottoms that need to be compared are the slope in the X-Y plane, the y-intercept and "does one line lie within the other?". The first two properties can be compared if the equation of the lines in cartesian form are calculated. The equation is

\[ y = m \times x + b \]  \hspace{1cm} (2.7)

where

\[ m \] = slope, and

\[ b \] = y-intercept.
If a line is parallel to the $Y$ axis the above equation breaks down since the line has infinite slope and does not intersect the $Y$ axis. A different form of the equation had to be used to overcome these problems and is shown below

$$A \times X + B \times Y + C = 0$$ \hspace{1cm} (2.8)
Another possibility was to use a parametric form of equation for the sides of the cubes. A parametric equation describes bounded geometry allowing the end points to be determined. A line in the X-Y plane is described by two equations that are a function of a parameter u. Generally the equation is expressed as
\[ y = f(x) \]
but in parametric form it is,
\[ x = x(u), \text{ and} \]
\[ y = y(u) \]
where u varies from zero to one.
A straight line has the form
\[ x = A \times u + B \]
\[ y = C \times u + D \]
(2.9)
where \( u = 0 \) to \( 1 \),
B is the x coordinate of the start point,
D is the y coordinate of the start point,
A and C are the components of a vector parallel to the line.

If this form of the equation is used the Y intercept would have to be calculated since the equation does not give information with regard to this property. Also four constants would have to be stored for each equation were a cartesian form only uses three constants. For these reasons the cartesian representation of the line was used to
determine whether or not one cube adjoins another. Once adjoining cubes are determined the roof intersections can be calculated.

2.2.3 Interior Bearing

The bearing of a truss on an interior support will directly effect the forces in truss members and therefore is a very important detail to consider. The interior bearing locations for a truss can be identified after the Combine option has been select. To identify interior bearing the Ibearing option in Figure 2.12 is selected. The Selection Menu in Figure 2.17 is displayed next. The three options of selecting trusses are Singles, Cube and Array. The Singles option allows the operator to select any number of trusses in any order. The Cube option selects all trusses on a cube and the Array option selects trusses in a sequence. With the trusses selected a prompt for the location of the first interior bearing is requested and then the second. The program supports a maximum of two interior bearing points for each truss.

2.3 Display Capabilities

To give the operator a realistic view of the building and the feeling of constructing it, a three-dimensional wire frame view of the building's walls and roofs are drawn on
the display screen as the support and roof data are entered. The orientation of the coordinate axes is shown in Figure 2.18. This orientation allows the front, top and left side faces for the building to be shown.

The orthographic projection method was used to display the buildings on the screen. This projection method was chosen because lengths and angles are accurately represented when the plan or elevation views of the building are displayed. Options for the Front, Right Side and Top views are present in the program. An Isometric View option is also available. It allows three faces of the building to be displayed with the relative proportions of the building maintained. An option to define any view is also present. The views provided are commonly used in engineering drawings. Other display options provided deal with scaling and translating of the view on the display screen. The options are Pan, Zoom and Ascale. The Pan options allows the translation of the view on the drawing window without changing the scale. The Zoom option allows an area on the drawing window to be translated to the center of the drawing window and scaled to occupy the entire drawing window. The Ascale option stands for Auto-scale. This option translates and scales the view so the entire building is shown and centered on the drawing window. An option to view truss profiles is available. The Vtruss option allows the operator to select a truss to be viewed and its fully
dimensioned profile will be displayed. A typical truss profile is shown in Figure 2.19. All these options are part of the Display Menu which is shown in Figure 2.20.

The display options provided can be used by the operator to view the roof and truss profiles to ensure the roof will yield the desired appearance.

2.4 Output Capabilities

The capability to plot views and truss profiles is necessary for presentation purposes. Two approaches for identifying the view to be plotted were investigated. The first being a menu of views that can be plotted and the selection of an option would produce a plot. The second is having the operator display the desired view on the screen and a series of key presses to have the contents of the screen plotted. The two approaches are nearly identical but the second approach allows the operator to view the plot before it is produced. This leads to fewer unwanted plots being produced. For this reason the second approach was taken. In the program plots are produced by first selecting the Drwg (Drawing) option from the Main Menu. This causes the Drawing Menu in Figure 2.21 to be displayed. The Display option is selected to set the screen for plotting. The Display Menu is the same one used during the viewing of the building and truss profiles. Once a desired view is on
the screen the escape key is pressed and the Drawing menu reappears. Selecting the Plot option causes the contents of the screen to be plotted.

The Level option on the Drawing Menu is used to turn levels on or off. The Level Menu is shown in Figure 2.22. The lines drawn by the program to represent a building can be classified in terms of what they define. For example, some lines represent the top plates or trusses. Each one of these classifications are kept on a separate level by the program and can be made visible or invisible through the Level option. Selecting the Truss option on the Level Menu will cause subsequent views and plots to be produced without trusses being drawn.

One of the most important results of the program was to be a drawing of a truss layout plan. The information needed on a plan are the location of trusses, group label on each truss and a method of indicating dimensions. The truss layout plans are necessary during the construction phase of a building. The plan will be used by the truss installers to determine the position of the trusses in the building. The method of dimensioning used is to give the overall width and length of the building and to have the building plotted to a common architectural scale. This will allow other building features to be measured from the plan with a architectural scale. The trusses are organized into groups
according to their profile and support conditions. Each group is given a unique group letter. A typical plot of a layout plan is shown in Figure 2.23.

The Print option produces a report on the trusses of a building. The information given in the reports are the quantity of each truss, identification of hip girders and other data that defines the truss profile. A sample page of a report is shown in Figure 2.24. The report summarizes the trusses for the truss manufacturer.
Chapter III

THREE-DIMENSIONAL GRAPHICS

3.1 General

TrussCAD uses three-dimensional wire frame modeling. This means that the buildings drawn by TrussCAD are made of lines representing the boundaries of the building. The lines are defined in an XYZ coordinate space. If the coordinates of line end points can be manipulated or transformed to cause a change in position, orientation and scale of a building on the display screen, different views of a building or a portion of a building can be produced. There is a need for a systematic method of performing these transformations. A computer is well suited for matrix operations making a matrix method of describing the transformations the most convenient. The three basic types of transformations are translation, rotation, and scaling. These three transformations are called modeling transforms. With modeling transforms the viewer is kept at one location and the objects are transformed to enable the viewer to see different views of the object.
There is an alternate approach of keeping the object at one location and moving the viewer about the object. The transformations that achieve this are called viewing transformations. In both the modeling and the viewing transformation approaches there is extensive use of simple matrix mathematics. There are no obvious advantages between the two approaches in terms of programming, speed that a new view can be generated or the ease of program operation for an end user. Indeed, the matrix calculations required for the two approaches are virtually identical. The two approaches are described in detail in many books that deal with three-dimensional graphics. References [2] and [3] are examples of such books.

In this project the modeling transform approach is used. For completeness it is summarized below.

3.2 Transformations

3.2.1 Translation

A translation is a linear movement of an object or point from its initial position to any other position. The point at coordinate location \((x', y', z')\) is translated to \((x', y', z')\) by adding distances of \(T_x\), \(T_y\) and \(T_z\) to the initial coordinates. Therefore \((x', y', z')\) are:
\[ x' = x + T_x \]
\[ y' = y + T_y \]
\[ z' = z + T_z \]  
(3.1)

This is illustrated in Figure 3.1. The translation triple \((T_x, T_y, T_z)\) is called the translation vector. This form of describing a translation cannot be expressed in a matrix form involving matrix multiplication if simple cartesian coordinates are used. A matrix multiplication form is appropriate if more than one transformation is to be applied. (See Section 3.2.4 below.) If points are expressed as homogeneous coordinates, translations written in a matrix form can be applied through multiplication of the homogeneous coordinate matrix by the transformation matrix to yield the transformed homogeneous coordinate matrix. The homogeneous coordinate representation of a point \((x,y,z)\) is \((x_h,y_h,z_h,k)\) where

\[ x = x_h / k \]
\[ y = y_h / k \]
\[ z = z_h / k \]  
(3.2)

For simplicity, the parameter \(k\) is set to unity. Therefore, point \((x,y,z,1)\) is translated to \((x',y',z',1)\).

Equation (3.1) in matrix form is,

\[
\begin{bmatrix}
  x' \\
  y' \\
  z' \\
  1
\end{bmatrix} =
\begin{bmatrix}
  x \\
  y \\
  z \\
  1
\end{bmatrix}
\begin{bmatrix}
  1 & 0 & 0 & 0 \\
  0 & 1 & 0 & 0 \\
  0 & 0 & 1 & 0 \\
  T_x & T_y & T_z & 1
\end{bmatrix}
\]  
(3.3)
3.2.2 Rotation

The transformation of a point on an object along a circular path is a rotation about a specified axis. The geometrical aspects of the rotation, $\theta$, about the $Z$ axis for the point $(x, y, z)$ to $(x', y', z')$ are shown in Figure 3.2. Using standard trigonometric identities,

$$x' = r \cos(\phi + \theta)$$

or

$$x' = r \cos\phi \cos\theta - r \sin\phi \sin\theta$$

or

$$x' = x \cos\theta - y \sin\theta$$

$$y' = r \sin(\phi + \theta)$$

or

$$y' = r \sin\phi \cos\theta + r \cos\phi \sin\theta$$

or

$$y' = y \cos\theta + x \sin\theta$$

$$z' = z$$

The matrix representation of the rotation about the $Z$ axis is

$$\begin{bmatrix} x' & y' & z' & 1 \end{bmatrix} = \begin{bmatrix} x & y & z & 1 \end{bmatrix} \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3.5)

Similarly the matrix representation for the rotation about the $X$ axis and $Y$ axis, respectively, are

$$\begin{bmatrix} x' & y' & z' & 1 \end{bmatrix} = \begin{bmatrix} x & y & z & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\theta & \sin\theta & 0 \\ 0 & -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(3.6)

and
\[
\begin{bmatrix}
  x' \\ y' \\ z' \\ 1
\end{bmatrix} = \begin{bmatrix}
  x \\ y \\ z \\ 1
\end{bmatrix} \begin{bmatrix}
  \cos \theta & 0 & -\sin \theta & 0 \\
  0 & 1 & 0 & 0 \\
  \sin \theta & 0 & \cos \theta & 0 \\
  0 & 0 & 0 & 1
\end{bmatrix}
\]

(3.7)

A rotation is positive if it is in a counterclockwise direction when viewed from a positive position along the axis looking towards the origin. This shown in Figure 3.3

3.2.3 Scaling

The transformation that alters an object's size is called scaling. Each line end point, \((x, y, z)\), is operated upon by scaling factors \(S_x, S_y, \) and \(S_z\) to yield the transformed point \((x', y', z')\). The transformed point is:

\[
\begin{align*}
  x' &= x \times S_x \\
  y' &= y \times S_y \\
  z' &= z \times S_z
\end{align*}
\]

(3.8)

In matrix form, this can be achieved by

\[
\begin{bmatrix}
  x' \\ y' \\ z' \\ 1
\end{bmatrix} = \begin{bmatrix}
  x \\ y \\ z \\ 1
\end{bmatrix} \begin{bmatrix}
  S_x & 0 & 0 & 0 \\
  0 & S_y & 0 & 0 \\
  0 & 0 & S_z & 0 \\
  0 & 0 & 0 & 1
\end{bmatrix}
\]

(3.9)

Scale factors of less than one cause a reduction in size while scale factors greater than one cause enlargements. If all scale factors are set to the same value, a uniform
scaling is produced, and the relative proportions of the object are maintained. If the scale factors are unequal, the object will appear in a distorted fashion.

3.2.4 Composite Transformations

A series of transformations may be represented in a single matrix which will be called the master modeling matrix, \([ M ]\). This matrix is equal to the product of the transformation matrices. The procedure for arriving at the final form of the master modeling matrix starts with setting it equal to the identity matrix. Thus,

\[
[M] = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\] (3.10)

Each time a transformation is given the transformation matrix \([ T ]\) is constructed according to equation 3.3, 3.5, 3.6, 3.7 or 3.9. The current master modeling matrix is then multiplied by the transformation matrix to yield an updated master modeling matrix. Thus,

\[
[M] = [M] [T]
\] (3.11)

When all transformations have been included in the master modeling matrix, the transformed homogeneous coordinate \((x', y', z', 1)\) can be obtained for each point on an object by

\[
[x' \ y' \ z' \ 1] = [x \ y \ z \ 1] [M]
\] (3.12)
For example, if point \((x, y, z)\) is to be transformed first by a translation \((T_x, T_y, T_z)\) and then by a rotation about the \(X\) axis by an angle \(\theta\), the master modeling matrix is calculated as shown below:

Master modeling matrix after the translation

\[
[M] = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 \\
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
T_x & T_y & T_z & 1
\end{bmatrix}
\]

\[(3.13)\]

Master modeling matrix after the rotation

\[
[M] = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
0 & 0 & 1 & 0 \\
T_x & T_y & T_z & 1
\end{bmatrix}
\begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \theta & \sin \theta & 0 \\
0 & -\sin \theta & \cos \theta & 0 \\
0 & 0 & 0 & 1
\end{bmatrix}
\]

\[
[M] = \begin{bmatrix}
1 & 0 & 0 & 0 \\
0 & \cos \theta & \sin \theta & 0 \\
0 & -\sin \theta & \cos \theta & 0 \\
T_x & T_y \cos \theta - T_z \sin \theta & T_y \sin \theta + T_z \cos \theta & 1
\end{bmatrix}
\]

\[(3.14)\]

In using the above procedure, it should be noted that the order in which the successive transformations are applied is important because in general matrix multiplications are not commutative. This means

\[
[X] [Y] \neq [Y] [X]
\]
3.3 Three-dimensional Viewing

The building images created by TrussCAD are three-dimensional but the computer screen, that images are displayed on, is only two-dimensional. Two methods of projecting the three-dimensional images onto a two-dimensional screen are by parallel and by perspective projections. In both cases points will be projected along lines to intersect with a projection plane. The points on the projection plane or viewing surface are then converted to screen coordinates.

3.3.1 Parallel Projection

Using parallel projections, views of objects can be produced while maintaining their relative dimensions. Examples of some possible views are top, right side and front. The disadvantage of this method is that the appearance of a three-dimensional object is not a realistic one. This is apparent when an observer looks down a long flat road. In this example, the edges of the road appear to converge at a point. In addition, fence posts located further along the road appear to be shorter than those closer to the observer. The image of this view produced by a parallel projection is shown in Figure 3.4. Note that the road edges do not converge and the fence posts are the same
height. This illustrates that views produced by a parallel projection maintain relative sizes and that they are not realistic. Such views do not provide any depth perception.

A specific type of parallel projection is the orthographic projection. It projects points along parallel lines that are perpendicular to the projection plane. This is the method of projection used by engineers to produce plan and elevation views of objects.

In Figure 3.5 the front view of an object is produced by projecting the end points of each line back on to the XY plane. The projected point \((x_p, y_p, z_p)\) of point \((x, y, z)\) is

\[
\begin{align*}
  x_p &= x \\
  y_p &= y \\
  z_p &= 0
\end{align*}
\] (3.15)

The z coordinate is simply neglected in this view.

3.3.2 Perspective Projection

In a perspective view any set of parallel lines that are not parallel to the projection plane are projected into converging lines. The point at which they converge is the vanishing point or center of projection. A perspective projection gives a realistic view but does not maintain relative dimensions. If an image of the road described in the previous Section is produced using a perspective projection, the road edges would appear to converge and the fence posts would be smaller the further along the road they
are located. This is shown in Figure 3.6 which illustrates
that perspective projection produce realistic images but do
not maintain relative dimensions. This view provides an
apparent depth perception.

In this method all points are projected along lines that
converge at the center of projection. The equations to
calculate the projected point \((x_p, y_p)\) of \((x, y, z)\) is develop
with the aid of Figure 3.7.

From the YZ plane

Triangles ABC and ADE are similar triangles. Thus

\[
\frac{AC}{BC} = \frac{AC + CE}{DE}
\]

\[
\frac{d}{Y_p} = \frac{d + z}{y}
\]

\[
Y_p = \frac{d \times y}{d + z}
\]

(3.16)

From the XZ plane

Triangles FHG and FIJ are similar triangles. Thus

\[
\frac{FG}{GH} = \frac{FG + GJ}{JI}
\]

\[
\frac{d}{x_p} = \frac{d + z}{x}
\]

\[
x_p = \frac{x \times d}{d + z}
\]

(3.17)

A comparison of the front view of a wire frame cube
drawn by the orthographic and perspective projection method
is shown in Figure 3.8. In the perspective drawing the
lines BF, CG, DH and AE will converge at one point. Also
sides ABCD and EFGH are projected to different sizes. The
appearance of the rectangle EFGH in the front view using a perspective projection would not be acceptable for engineering purposes. For this reason orthographic projections was used in this work.

3.4 Programming Approach

The three-dimensional graphics subroutines were written in Assembler for speed of operation. They were written by Dr. N. Wilson but are undocumented other than for information provided in this thesis. This programming is heavily dependent on the math co-processor for many of the mathematical operations. The math co-processor was used for speed and accuracy of calculations.

The first step in drawing a line is to set the modeling matrix. There are two modeling matrices, one being the master and the other a submatrix. The matrices have a size of four by four. Each transformation is passed to the appropriate subroutine and placed into the submatrix. Then the master modeling matrix is multiplied by the submatrix to yield a new master modeling matrix. This process means transformations will accumulate in the master modeling matrix. The calculations on the master modeling matrix are performed with ten byte real numbers on the math co-processor. It was noted in Section 3.2.4 that matrix multiplication is not commutative; therefore, the order in
which the transformations are specified will affect the form of the master modeling matrix. This in turn will affect the appearance of the object on the display.

The next step is to identify the start and end points of a line. There are two subroutines, Move3 and Draw3, in the programming that are used in drawing lines defined in three-dimensional (3D) space. For both of these subroutines, the coordinates of a point, \((x, y, z)\), are entered into the subroutine. Homogenous coordinates of the point \((x, y, z)\) are multiplied by the master modeling matrix to give the 3D transformed co-ordinates, \((x', y', z')\). Two coordinate axis systems are used: one is the world coordinate system, \(XYZ\), and the other is the transformed coordinate system, \(X'Y'Z'\). If the master modeling matrix was set to the identity matrix the two coordinate systems would coincide. Once the master modeling matrix is altered by defining a transformation, the world coordinate axis system is transformed relative to the transformed coordinate system. This is illustrated in Figure 3.9. In Figure 3.9(a) the master modeling matrix is set to the identity matrix. In Figure 3.9(b) the result of a translation, \((T_x, T_y, T_z)\), is shown. In Figure 3.9(c) the result of a succeeding rotation about the \(Z\) axis by an angle \(\theta\) is shown. Note that the rotation is about the transformed coordinate axis.
The transformed 3D points are then converted to two-dimensional (2D) points by the chosen projection method. In this project, orthographic projections were always used, although the graphics software also supports perspective projections. (Perspective projections are generally more confusing when viewed on the computer screen.) The projection plane used is the X'Y' plane. This means the viewer can be considered to be on the positive Z' axis looking towards the origin. The 2D points are determined by simply neglecting the Z' coordinate of the points. The points are then converted to screen coordinates. In the case of a Move3 instruction, the point is saved as the current point; for a Draw3 instruction, a line is drawn from the current point to the point given by the Draw3 instruction and the current point is then updated. When the line is drawn it is clipped by the screen boundaries and a text window. The clipping is performed by checking each pixel that must be activated for a line to ensure it is within the drawing area. If it is not within the drawing area the pixel is not activated. Bresenham's line algorithm was used to generate the pixel positions of a line. The algorithm is described in Reference 2.

In summary, the steps necessary to draw a line are

a) Set the modeling matrix,

b) Determine the start and end points,

c) Multiply the start and end points by the modeling matrix to yield the transformed three-dimensional
points,

d) Project the transformed points onto the projection plane and convert to screen coordinates, and
e) Draw the line by filling in the pixels between the end points. Clip the lines with respect to the screen limits and text portion of the screen.

3.5 Summary of Graphics Subroutines

The graphics subroutines, with a brief description of each one, are listed in the following three sections. The data type of the subroutine arguments are classified according to their first letter. If the first letter of an argument is "I" the argument is a four byte integer. Otherwise, it is a four byte real number.

3.5.1 Modeling Matrix Subroutines

The following subroutines are used to set the modeling matrix.

a) MDROTX(irotx) rotates object about the X axis by the value of irotx.
b) MDROTY(iroty) rotates object about the Y axis by the value of iroty.
c) MDROTZ(irotz) rotates object about the Z axis by the value of irotz.
d) MDSCALE(iscalex, iscaley, iscalez) changes the X, Y,
and Z scaling components of the master modeling matrix by the values of iscalex, iscaley and iscalez.

e) MDTRAN(itranx,itrany,itranz) changes the translation components of the master modeling matrix by the values of itranx, itrany and itranz.

f) MDIDEN sets the master modeling matrix to the identity matrix.

3.5.2 Line Drawing Subroutines

The following subroutines are used during the drawing of a line.

a) DRAW3(ix,iy,iz) draws a line from the current point to (ix,iy,iz). Then it updates the current point to (ix,iy,iz).

b) MOVE3(ix,iy,iz) updates the current point to (ix,iy,iz).

c) COLOR(icolor) sets the color index. The lines drawn as a result of this command will have a color dependent on the color index, the present color of the pixels on the line and the current value of the drawing mode.

d) LINFUN(imode) sets the drawing mode. For the following values of imode the drawing mode is given.

0 Replace Mode- draws a line in the current color index.
1. Complement Mode - draws a line in a color that is the complement of the present pixel color. The complement of a binary number is determined by reversing the zeros and ones of the number. For example, if the present pixel color is 1101, then its complement would be 0010. This mode can be used for erasing.

2. XOR Mode - draws a line in a color that is the result of the logical operation XOR (exclusive OR) between the color index and current color of the pixel. The logic of an XOR operation can be stated as; A is true if B or C is true but not both. If one is true and zero is false then the XOR between binary numbers 0101 and 1100 is 1001. This mode can be used for erasing.

3. OR Mode - draws a line in a color that is the result of the logical operation OR between the color index and current pixel color. The logic of an OR operation can be stated as; A is true if B and or C is true. The OR between the binary numbers 0101 and 1100 is 1101.

4. AND Mode - draws a line in a color that is the result of the logical operation AND between the color index and current color of the
pixel. The logic of the AND operation can be stated as: A is true if B and C are true.
The AND between the binary numbers 0101 and 1100 is 0100.
f) PROJECT(iangle) sets the projection method to either orthographic or perspective. A value of zero for iangle sets the projection method to orthographic which was used in this project.
g) GET3(rx,ry,rz) returns the transformed 3D location of the current point.
h) GET2(rx,ry) returns the 2D location of the current point.
i) SMOVE(ixs,iys) changes the 2D current point to (ixs,iys). The arguments are given in terms of screen coordinates. The screen coordinate origin is the top left corner of the screen with the lower right corner having the coordinates (639,479).
j) SDRAW(ixs,iys) draws a line from the 2D current point to (ixs,iys). The 2D current point is then updated to (ixs,iys).
k) GETS(ixs,iys) returns the 2D location of the current point.

The drawing modes used in TrussCAD were the Replace mode for general line drawing and the XOR mode for erasing lines. The last three subroutines were used during the dimensioning
of trusses to position text and draw dimension lines and arrow heads. Also they were used to calculate the points for plotting purposes.

3.5.3. Control Subroutines

These subroutines control display characteristics.

a) INITGR changes the display mode of the screen to graphics mode.

b) TEXTMODE changes the display mode of the screen to character mode.

c) TWPOS(ixlow,iylow,ixhigh,iyhigh,ixx,iyy) defines the location of a text window with screen coordinates of the opposite window corners being (ixlow,iylow) and (ixhigh,iyhigh). The last two arguments are not used. The arguments are given in terms of screen coordinates. The origin is the lower left corner of the screen with the positive X axis along the bottom and positive Y axis along the left side.

d) TWVIS(istate) enables line clipping at the lower edge of the text window if istate is one. If istate is zero line clipping is disabled.

e) ZOOM(ixcen,iycen,rscale,iflag) is used to change the size and location of the building on the display screen. Iflag is set to one to activate zooming and zero to disable zooming. The screen location
(ixcen, iycen) is the point that will be positioned at the center of the screen. The rscale argument is the scale factor of the new display.

The Zoom subroutine is used in the Zoom, Ascale (auto-scale) and Pan commands. In the Pan command only the first two arguments are changed. The Zoom subroutine operates on the screen coordinates and takes the center of the drawing area to be at the screen location (320, 240). The equations it employs to calculate new points are

\[
\begin{align*}
ix_{\text{new}} &= 320 + (ix_{\text{old}} - ix_{\text{cen}}) \times rscale \\
iy_{\text{new}} &= 240 + (iy_{\text{old}} - iy_{\text{cen}}) \times rscale
\end{align*}
\] (3.18)

where \(ix_{\text{new}}, iy_{\text{new}}\) = the screen coordinates calculated by the zoom subroutine

\(ix_{\text{old}}, iy_{\text{old}}\) = the previous screen coordinates

\(ix_{\text{cen}}, iy_{\text{cen}}\) = screen coordinates (240, 320)

\(rscale\) = scale factor

In this project the center of the drawing area never coincides with the center of the display screen. The presence of menus and data entry areas causes the center of the drawing area in the vertical direction to be lower than the display screen center. For this reason the value of the \(iy_{\text{cen}}\) sent to the Zoom subroutine must be altered. The new value of \(iy_{\text{cen}}\) is equal to
\[ iy'_{\text{cen}} = iy_{\text{cen}} + \text{idiff} / \text{rscale} \]  \hspace{1cm} (3.19)

where

\[ \text{idiff} = \text{the difference between the center of the display screen and drawing area.} \]
Chapter IV

RESULTS AND DISCUSSION

4.1 General

The program, TrussCAD, is menu driven and Figure 4.1 is a flow chart of the menu structure. An outline of a typical session with TrussCAD would be:

a) Select the File option on the Main Menu and activate a file.

b) Select the Support option on the Main Menu and enter cube data. Choose the Finished option to return to the Main Menu.

c) Select the Roof option on the Main Menu and enter roof data. Choose the Combine option to join roofs and generate truss profiles and layout. Choose the Display option to display views of the building and truss profiles. Edit the roofs if necessary. Choose the Finished option to return to the Main Menu.

d) Select the Drwg (Drawing) option on the Main Menu and choose the Display option to set the view to be plotted. Choose the Plot option to plot the currently displayed view. Choose the Finished option to return to the Main Menu.
e) Select the Print option on the Main Menu to have a report on the building printed.
f) Select the Exit option on the Main Menu to close the active file and return to the operating system.

This is schematically shown in Figure 4.2.

A tutorial session for the program is in Appendix D. In the tutorial, step by step instructions are given for the entry of a two storey home. The purpose of the tutorial is to demonstrate the use of the options available in TrussCAD. The tutorial covers the following topics:

a) Support data entry,
b) Editing of support data,
c) Roof data entry,
d) Editing of roof data,
e) Entry of interior bearing,
f) Displaying results,
g) Plotting results,
h) Printing reports, and
i) File management.

4.2 Programming

The three-dimensional graphics subroutines were written in assembler for speed of operation. The 8088 and 8087 instruction sets were used.
The other programming was written in Microsoft Fortran Version 4.01. This version of Microsoft Fortran has interlanguage calling support. This allows future subroutines of the program to be written in Pascal, C or Assembler programming languages. There are several subroutines written in Assembler to carry out tasks that would be difficult or impossible to perform with Fortran. They were written by Dr. N. Wilson.

The program to date has been tested on five different computer configurations and was found to operate correctly on each one. The computer configurations are:

a) IBM AT, 8 MHz clock speed,
   80287 math co-processor,
   640 kilobytes of Random Access Memory (RAM)
   ATI Technologies Inc. Enhanced EGA Wonder Video Display Card in VGA compatible mode,
   NEC Multisync Monitor,
   Hard disk drive,

b) IBM XT Compatible, 10 MHz clock speed,
   8087 math co-processor,
   640 kilobytes of Random Access Memory (RAM)
   Everex Video Display Card in VGA compatible mode,
   NEC Multisync Monitor,
   Hard disk drive,
c) IBM XT Compatible, 8 MHz clock speed,
   8087 math co-processor,
   640 kilobytes of Random Access Memory (RAM)
   NEC GB Video Display Card in VGA compatible mode,
   NEC Multisync Monitor,
   Hard disk drive,

d) IBM System 2 Model 50, and

e) IBM System 2 Model 60.

Other display card-monitor combinations have not been
tested; however a minimum requirement would be that the
combination must be capable of supporting VGA mode 12(hex).

4.2.1 House File

TrussCAD produces two types of files which store the
support, roof and truss data for a building.

The file that stores support and roof data is called a
house file. By storing this data, the user can return to
previous work at a later time to finish or change it. The
file has a file name extension of ".HSE" and is produced
after the Finish Option in the Roof or Support Menu is
selected. The support data stored in the file are the world
coordinates of each cube's top four vertices. The roof data
stored in the file are the overhang, cantilever, heel
height, pitch, truss spacing, truss setbacks, truss
direction and roof style of each cube. The operator and
description given when a file is first activated and the
time and date that the file was last activated are also
stored.

The file is a formatted ASCII random access file. The
exact organization of the data in the file is given in
Appendix E.

4.2.2 Truss File

The file that stores profile data for each truss is
called a truss file. This file also stores the total number
of trusses in the building and the number of trusses related
to each cube. The file has a file name extension of ".TRU".
It is produced after the Finish Option of the Roof Menu is
selected.

The file is a formatted ASCII random access file. The
exact organization of the data in the file is given in
Appendix E.

The data stored in the house and truss files could be
used as the input for a truss analysis program. Typical
questions asked by an interactive truss analysis program
are:

a) Job name?
b) Span (ft, inches, /16) ?
c) Spacing (inches) ?
d) Heel height, left & right (inches) ?
e) Overhang, left & right (inches) ?
f) Cantilever, left & right (inches) ?
g) Pitch, left & right ?
h) Location of interior bearing ?
i) Loading (lb / square ft) ?
j) Number of plies ?
k) Top chord lumber size and grade ?
l) Bottom chord lumber size and grade ?
m) Web lumber size and grade ?
n) Top chord panel lengths (ft, inches) ?
o) Bottom chord panel lengths (ft, inches) ?

The answers to the first eight questions can be found in the truss and house files created by TrussCAD. This would decrease the amount of information the truss designer has to enter into the truss analysis program. To take advantage of this, additional programming is necessary to extract and organize data from the house and truss files in a form that a truss analysis program can use. This programming is left for the user to develop.

4.2.3 Program Characteristics

The program calculates and operates with points on a building in a XYZ coordinate space. This approach enables the use of modeling transformations to display any required view of a building or truss profile. The menu structure
produces an interactive and user friendly program. The menu line lists the currently available options and the prompt line gives the operator information about what data to enter or option to select. The data entry areas are organized to allow the operator quick data entry and easy viewing of data for verification purposes. The File Menu shown in Figure 4.3 adds convenience to the program by allowing file management within TrussCAD. The menu includes commands to copy or delete files from within TrussCAD. The View option is useful when the operator has forgotten the contents of a particular house file. The option displays the operator’s name, description and time and date the file was last edited. The Spec option allows the operator to view different directories on any disk drive.

TrussCAD can accommodate three different roof styles:

a) hip,
b) gable, and
c) flat.

The available truss profiles are:

a) triangular,
b) flat,
c) stub,
d) hip, and
e) dual pitch.

The trusses can have one or two interior supports.
4.3 Benefits

The two parties who will benefit from this program are the truss fabricators and truss designers. Truss fabricators by using this program, will computerize the process of calculating truss layout and truss profiles. Time savings are achieved during revisions and preparation of truss layout plans. There is a requirement in a growing number of municipalities that the truss designer or fabricator must provide a truss layout plan to municipal inspectors [4]. The plan should show the position of the trusses and indicate trusses profiles. The plots produced by TrussCAD meet this requirement. A typical truss layout plan was shown in Figure 2.23. The top view of the building was plotted to the largest possible scale with the bottom chord of each truss plotted and labeled with its group letter. A typical report produced by TrussCAD is shown in Figure 2.24. It summarizes profile data for each truss group.

The ability to view the trusses and elevations of the building lets the operator interactively see how roofs intersect. This is illustrated in Figure 2.22 where a front view of a building made of two cubes is displayed. Figure 2.20 and 2.21 show top and isometric views of the same building. The operator can check to ensure that the ridge
and eaves lines intersect properly by displaying the front view. This reduces errors by giving the operator a visual check of the data that was entered.

A more efficient communication link with the truss designer will be realized when the house and truss files are linked to existing truss analysis programs. The data produced by TrussCAD could be sent over existing telephone lines and be received by the truss designer. The data would then be the input for a truss analysis program. This would eliminate transcribing errors of data during telephone conversations. Also courier services to transfer data would no longer be needed. A more efficient communication link would benefit the truss fabricator and truss designer by transferring data with greater speed and reliability. An additional benefit to the truss designer would be a reduction in data entry for a truss analysis program.

An architect using this program would benefit from the ability to display any view of a given roof. This would be useful in the architectural design of a roof to determine what pitches, overhangs, cantilevers and heel heights should be used to yield a desired appearance.
Chapter V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The objective of this project was to develop a computer program on a personal computer that can be used by architects, design engineers and truss fabricators to generate truss profiles and truss layout. The program TrussCAD has achieved this objective. The program can determine the truss layout and truss profiles for the following roof styles:

a) hip,
b) gable, and
c) flat.
The trusses can have the following profiles:
a) triangular,
b) flat,
c) hip,
d) stub, and
e) dual pitch.
Other conclusion that can be made are:

a) The use of three-dimensional graphics enables any view of a building or truss profile to be produced so a visual check of a roof can be performed.

b) The use of menus and a prompt line produces a interactive user friendly menu driven program.

c) The ability to perform file management within the program adds to the overall convenience of TrussCAD.

d) The truss layout plans produced by TrussCAD can be used during the erection of trusses to determine their location in a building.

e) The ability to store and edit data entered into the program make revisions of a roof design possible.

f) Interior bearing of trusses can be specified.

g) The data stored by the program could be used as the input for a truss analysis program.

h) The program has been proven to operate correctly on five different computer configurations. The common components of these computer configurations are:

i) 8088 or 80286 micro-processor,

ii) 8087 or 80287 math co-processor,

iii) 640 kilobytes of random access memory (RAM)

iv) VGA video display card or EGA video display card capable of producing VGA video display mode 12 (hex),
v) VGA monitor or monitor capable of displaying VGA video display mode 12 (hex), and
vi) hard disk drive.

5.2 Recommendations

It is proposed that further development of this program should concentrate on the following areas:

a) The entry of exterior load bearing walls that are not parallel to the X or Y axes,
b) The calculation and storage of jacks of a hip roof,
c) The entry of different roof styles (for example, dutch hip),
d) The entry of specific types of interior bearings (for example, columns, beams, etc.),
e) The entry of different truss profiles (for example, scissors trusses), and
f) Overcome memory limitations through the use of overlays. An alternative is to determine if the program can be compiled for operation in Operating System/2's protected mode.
Figure 1.1: The Relationship Amongst Parties in the Truss Industry
THE QUALITY OF THIS MICROFICHE IS HEAVILY DEPENDENT UPON THE QUALITY OF THE THESIS SUBMITTED FOR MICROFILMING.

UNFORTUNATELY THE COLOURED ILLUSTRATIONS OF THIS THESIS CAN ONLY YIELD DIFFERENT TONES OF GREY.
Figure 2.1: Main Menu
Figure 2.2: Cross-Section of a Typical One Storey Building
Figure 2.3: Building Broken Down Into Cubes
Figure 2.4: Cube Vertices
Figure 2.5: Support Data Entry Area
Figure 2.6: Typical Roof
Figure 2.8: Step-Down Hip System (after Truswall Systems Corporation Publication, Truss Facts)
Figure 2.11: California Hip System (after Truswall Systems Corporation Publication, Truss Facts)
Figure 2.12: Roof Menu

Figure 2.13: Prompt for Span Direction
Figure 2.14: Roof Data Entry Area
Figure 2.15: L-Shaped Building
Figure 2.16: Adjoining Cubes
Choose the selection method for indicating which trusses will have net bearing

Figure 2.17: Selection Menu
Figure 2.18: Orientation of Axes
Figure 2.19: Truss Profile

Figure 2.20: Display Menu
Figure 2.21: Drawing Menu

Figure 2.22: Level Menu
<table>
<thead>
<tr>
<th>GROUP A</th>
<th>GROUP B</th>
<th>GROUP C</th>
<th>GROUP D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Girder setback (in)</strong> = 48.00</td>
<td><strong>Spacing (in)</strong> = 24.00</td>
<td><strong>Spacing (in)</strong> = 24.00</td>
<td><strong>Spacing (in)</strong> = 24.00</td>
</tr>
<tr>
<td>Quantity = 2</td>
<td>Span 19 ft 6 in 0 16th</td>
<td>Span 19 ft 6 in 0 16th</td>
<td>Span 19 ft 6 in 0 16th</td>
</tr>
<tr>
<td><strong>Interior Bearing Left</strong></td>
<td><strong>Pitch</strong></td>
<td><strong>Pitch</strong></td>
<td><strong>Pitch</strong></td>
</tr>
<tr>
<td><strong>Heel height</strong></td>
<td>4.00/12</td>
<td>3.94 in</td>
<td>4.00/12</td>
</tr>
<tr>
<td><strong>Overhang</strong></td>
<td>3.94 in</td>
<td>24.00 in</td>
<td>3.94 in</td>
</tr>
<tr>
<td><strong>Cantilever</strong></td>
<td>24.00 in</td>
<td>0.00 in</td>
<td>24.00 in</td>
</tr>
<tr>
<td><strong>Cantilever</strong></td>
<td>0.00 in</td>
<td>24.00 in</td>
<td>0.00 in</td>
</tr>
<tr>
<td><strong>Pitch</strong></td>
<td>Right</td>
<td><strong>Pitch</strong></td>
<td>Right</td>
</tr>
<tr>
<td><strong>Heel height</strong></td>
<td>4.00/12</td>
<td><strong>Heel height</strong></td>
<td>4.00/12</td>
</tr>
<tr>
<td><strong>Overhang</strong></td>
<td>3.94 in</td>
<td><strong>Overhang</strong></td>
<td>3.94 in</td>
</tr>
<tr>
<td><strong>Cantilever</strong></td>
<td>24.00 in</td>
<td><strong>Cantilever</strong></td>
<td>24.00 in</td>
</tr>
<tr>
<td><strong>Cantilever</strong></td>
<td>0.00 in</td>
<td><strong>Cantilever</strong></td>
<td>0.00 in</td>
</tr>
</tbody>
</table>

**Figure 2.24: Typical Report**
Figure 3.1: Translation of a Point
Figure 3.2: Rotation About the Z Axis
Rotation About the X Axis

Rotation About the Y Axis

Rotation About the Z Axis

Figure 3.3: Positive Rotations
Figure 3.4: View of a Road Produced by the Parallel Projection Method
Figure 3.5: Front View Produced by the Orthographic Projection Method
Figure 3.6: View of a Road Produced by the Perspective Projection Method
Figure 3.7: Development of the Perspective Projection Method
Figure 3.8: A Comparison of a Front View Produced by the Orthographic and Perspective Projection Methods
A) Master Modeling Matrix Set To the Identity Matrix

Figure 3.9: World Coordinate Axis System Transformed Relative to the Transformed Coordinate Axis System
Figure 3.9: World Coordinate Axis System Transformed Relative to the Transformed Coordinate Axis System
C) World Coordinate Axis System Rotated Relative to the Transformed Coordinate Axis System

Figure 3.9: World Coordinate Axis System Transformed Relative to the Transformed Coordinate Axis System
Figure 4.1: Menu Listing
Figure 4.2: TrussCAD Program Flow Chart
Activate use [L] to select proc. Finished
Highlight a file in yellow then select option.

To display more files press Pg Up or Pg Dn
File search spec. = .hse

Figure 4.3: File Menu
APPENDIX A

DEFINITION OF TRUSS TERMS
BOTTOM CHORD An exterior truss member that establishes the lower edge of a truss. See Figure A.1.

BUTT CUT The length of the vertical segment of bottom chord. See Figure A.2.

CANTILEVER The horizontal distance from the exterior support to heel. See Figure A.1.

DUAL PITCH TRUSS A truss with unequal top chord pitches. See Figure A.3.

EAVES LINE Marks the lower edge of a roof. See Figure A.4.

GABLE ROOF A roof with two sloping sides. See Figure A.5.

HIP ROOF A roof with four sloping sides. See Figure A.6.

HIP RAFTER Structural roof member in which the end and side jacks frame into. See Figure A.7.

HEEL The end of the bottom chord where the top and bottom chord meet. See Figure A.1.

HEEL HEIGHT The vertical distance from the bottom of bottom chord to top of top chord measured at the end of the bottom chord. See Figure A.2.

INTERIOR BEARING An intermediate support for a truss. Usually a load bearing wall or column.

JACK Structural roof members used in a step-down hip system to frame from the first truss to the end wall. See Figure A.7.

NOMINAL HEEL HEIGHT It is the nominal width of the lumber used for the top chord. Assuming a normal butt cut of 0.25" and given the top chord pitch the heel height can be calculated. For example, if 2 x 4 lumber is used for a top chord the nominal heel height is 4 inches. See Figure A.2.

OVERHANG The horizontal distance from the end of bottom chord to the end of top chord. See Figure A.1.

PITCH A slope generally expressed as a ratio of vertical rise over a 12 inch horizontal run. See Figure A.1.

RIDGE LINE The line formed by the meeting of two sloping roof surfaces. See Figure A.4.

SETBACK The distance from the end wall to the first truss in a hip roof. See Figure A.7.
SPAN  The outside to outside horizontal distance between exterior supports. See Figure A.1.

STEP TRUSS  A truss with a top chord having a flat mid-section and a sloping section on both sides. Used in a step-down hip system to form the sloping roof surface at the end of a building. See Figure A.7.

STUB TRUSS  A truss with unequal heel heights. See Figure A.8.

TOP CHORD  An exterior truss member that establishes the upper edge of a truss. See Figure A.1.

TOP PLATE  The lumber nailed to the wall studs that are the supports for the roof. See Figure A.1.

TRUSS  A structure that carries loads by axial compression or tension in its members.

WEB  An internal member of a truss that joins the top and bottom chord. See Figure A.1.
Figure A.1: Truss Elements

- Top Chord
- Bottom Chord
- Top Plate
- Heel
- Cantilever
- Overhang
- Span
- Rise
- Webs
Figure A.2: Definition of Heel Height
Figure A.3: Dual Pitch Truss
Isometric View

Eaves Lines

Ridge Lines

Top View

Figure A.4: Eaves and Ridge Lines
Figure A.5: Gable Roof
Figure A.6: Hip Roof
Figure A.7: Step-Down Hip System (after Truswall Systems Corporation Publication, Truss Facts)
APPENDIX B

CALCULATIONS
Elevation of Eaves Line
From Figure B-1 using Triangle GFA, solve for Ze.

\[ \frac{\text{Pit}4}{12} = \frac{AF}{GF} \]

\[ \frac{\text{Pit}4}{12} = \frac{Ze + \text{Heel}4}{\text{Over}4} \]

\[ Ze = \frac{\text{Pit}4 \times \text{Over}4 - \text{Heel}4}{12} \]  

(B.1)

Location of Ridge Line
From Figure B-1 using Triangles ABC and DEC, solve for A1 and Z1.

Triangle ABC

\[ \frac{\text{Pit}4}{12} = \frac{BC}{AB} \]

\[ \frac{\text{Pit}4}{12} = \frac{Z1 - \text{Heel}4}{\text{Span}1 + \text{Cant}4 + \text{Cant}2 - A1} \]

\[ Z1 - \text{Heel}4 = \frac{\text{Pit}4}{12} \times (\text{Span}1 - \text{Cant}4 + \text{Cant}2 - A1) \]

\[ Z1 = \frac{\text{Pit}4}{12} \times (\text{Span}1 - \text{Cant}4 + \text{Cant}2 - A1) + \text{Heel}4 \]  

(B.2)

Triangle DEC

\[ \frac{\text{Pit}2}{12} = \frac{ES}{ED} \]

\[ \frac{\text{Pit}2}{12} = \frac{Z1 - \text{Heel}2}{A1} \]

\[ Z1 = \frac{\text{Pit}2 \times A1 + \text{Heel}2}{12} \]  

(B.3)

(B.2)=(B.3) Solve for A1

\[ \frac{\text{Pit}4}{12} \times (\text{Span}1 - \text{Cant}4 + \text{Cant}2 - A1) + \text{Heel}4 = \frac{\text{Pit}2 \times A1 + \text{Heel}2}{12} \]

\[ A1 = \frac{(\text{Pit}4 \times \text{Span}1 + \text{Pit}4 \times (\text{Cant}4 + \text{Cant}2) + 12 \times (\text{Heel}4 - \text{Heel}2))}{(\text{Pit}2 + \text{Pit}4)} \]  

(B.4)
Break Points on a Step Truss

From Figure B-2, B-3, and B-4, solve for Z1, A1 and A2.

Figure B-3 Triangle ABC, solve for Z1.

\[
\frac{\text{Pit}_1}{12} = \frac{CB}{BA}
\]

\[
\frac{\text{Pit}_1}{12} = \frac{Z1 - \text{Heel}_1}{\text{Setback} + \text{Cant}_1}
\]

\[
Z1 = \frac{\text{Pit}_1}{12} \times (\text{Setback} + \text{Cant}_1)
\] \hspace{1cm} (B.5)

Figure B-4 Triangle ABC, solve for A1.

\[
\frac{\text{Pit}_4}{12} = \frac{CB}{AB}
\]

\[
\frac{\text{Pit}_4}{12} = \frac{Z1 - \text{Heel}_4}{A1}
\]

\[
A1 = \frac{12}{\text{Pit}_4} \times (Z1 - \text{Heel}_4)
\] \hspace{1cm} (B.6)

Similarly

\[
A2 = \frac{12}{\text{Pit}_2} \times (Z1 - \text{Heel}_2)
\] \hspace{1cm} (B.7)
Figure B.2: Step-Down Hip System (after Truswall Systems Corporation Publication, Truss Facts)
Figure B.3: Section C-C
Figure B.4: Step Truss
APPENDIX C

EQUATION OF A LINE
From Figure C-1, where \((X_1, Y_1)\) and \((X_2, Y_2)\) are the endpoints of the line and \((X, Y)\) is any point along the line

**Triangle ABC**

\[
\frac{\text{Rise}}{\text{Run}} = \frac{CB}{AB} = \frac{Y_1 - Y_2}{X_1 - X_2} \tag{C.1}
\]

**Triangle ADE**

\[
\frac{\text{Rise}}{\text{Run}} = \frac{DE}{AD} = \frac{Y_1 - Y}{X_1 - X} \tag{C.2}
\]

\((C.1) = (C.2)\)

\[
\frac{Y_1 - Y}{X_1 - X} = \frac{Y_1 - Y_2}{X_1 - X_2}
\]

\[
(Y_1 - Y) \cdot (X_1 - X_2) = (Y_1 - Y_2) \cdot (X_1 - X)
\]

\[
Y \cdot (X_2 - X_1) + Y_1 \cdot (X_2 - X) = X \cdot \left(\frac{Y_2 - Y_1}{X_2 - X_1}\right) + X_1 \cdot (Y_1 - Y_2)
\]

\[
X \cdot (Y_1 - Y_2) + Y \cdot (X_2 - X_1) + Y_1 \cdot (X_1 - X_2) + X_1 \cdot \left(\frac{Y_2 - Y_1}{X_2 - X_1}\right) = 0
\]

\[
AX + BY + C = 0 \tag{C.3}
\]

where

\[
A = (Y_1 - Y_2)
\]

\[
B = (X_2 - X_1)
\]

\[
C = Y_1 \cdot (X_1 - X_2) + X_1 \cdot (Y_2 - Y_1)
\]
Figure C.1: Straight Line Equation in X-Y Plane
APPENDIX D

TRUSSCAD TUTORIAL
INTRODUCTION

General Screen Design

The display screen in TrussCAD is divided into two distinct areas. The top part is for text and the lower part is for drawing. The top part displays prompts, menu options and other data. The text part is broken down as follows:

Line 1: On line 1 the active file is displayed. In some cases if an option has been selected it will be noted on this line. There is other data that is displayed on this line and it will be described when necessary.

Line 2: This line has the menu options with a character highlighted in red in each option. Pressing this key selects the option.

Line 3: This is the prompt line. It gives instructions to help choose a menu option or enter data. This line should be read when unclear on how to proceed in the program.

Line 4 to 8: When these lines are not part of the drawing window they are used in the entry of support and roof data.

The remaining part of the screen is the drawing window. This is where the building and trusses are displayed.

Menu Selection

Each menu option has a character highlighted in red and pressing this key selects the option. Upper or lower case characters are accepted by TrussCAD.

Labeling Conventions

The cubes representing the load bearing walls have their vertices labeled in a counterclockwise direction when viewed from above. The vertex with the lowest X and Y coordinates is vertex 1. This is shown in Figure E.1.

The setback of a hip girder truss in a step-down hip system is the distance from the end wall to the first truss. The labeling convention for setbacks is shown in Figure E.2.
THE TUTORIAL

The tutorial presents the fundamentals needed for data entry to achieve the end result of a truss layout drawing and truss profile geometry. The tutorial is broken down into steps with each step further broken down into several points.

Figure E.3 and E.4 show the building that the tutorial uses to introduce TrussCAD to the operator. It is a house made up of four cubes with the largest cube representing a two storey section.
Step 1: Activating a File. The File Menu.

At the beginning of each TrussCAD session the first action to take is to activate a file. This makes it possible to save in a disk file the data that will be entered in the following steps. Also for plots or reports to be produced on a file the file must be active.

1. At the DOS prompt type "TRUSSCAD" RETURN to execute the program. Several messages are displayed and then the Main Menu appears at the top of the screen.

2. Select the FILE option on the Main Menu by pressing "F" and the File Menu is displayed along with a directory list for the current file search specification. In this case no files are listed since no files with an extension of 'HSE' have been created.

3. Select the ACTIVATE option and respond to the prompt, 'Activate file', by typing "trial1" RETURN.

4. The prompt, 'Enter house description', is displayed next. Type in "Cornwall File No 12345 Job No 54321" RETURN. The description can be up to forty characters in length.

5. Enter your name in response to the next prompt, 'Enter your name'. The file name is now displayed in the top left corner of the screen. The screen is then erased and the Main Menu reappears. Your name may also be up to forty characters in length.

This information is now stored in the file trial1.hse along with the system time and data.

Description of Other Options in the File Menu

CLOSE: Closes the active file allowing any other file to be activated.

VIEW: Displays the description, operator name, time and date of any file with an extension of 'HSE'.

COPY: Copies files with an extension of 'HSE'.

DELETE: Deletes any file.

SPEC: Gives control over the file search specification. The file search specification is used to determine which files to display. Wild cards and paths are permitted.

FINISHED: Causes the Main Menu to be displayed.
Step 2: Entering the Support Data. The Support Menu.

The top plates of the building are entered next through the Support Menu. In TrussCAD the exterior walls of a building are modeled as a series of cubes with the top of each cube representing the top plates.

1. Select the SUPPORT option and the Support Menu is displayed along with the Support Data Entry Area.

Lines 4 to 8 on the screen are the Support Data Entry Area. The area is divided into 12 cells for the XYZ coordinates of cube vertices. Movement in this area is through the arrow keys. The coordinate axis system is displayed in a light gray color on the drawing window with an orientation shown in Figure E.5.

Step 3: Preparation for Support Input.

The building's exterior walls are modeled as a series of cubes. The sides of the cubes must be parallel to the X or Y axis. Also the base of the cubes are taken to be at an elevation (Z coordinate) of zero.

1. Place the coordinate axes on the building. In this case place the origin at point A shown on Figure E.6. The base of the cubes can be assumed to be the finished grade line, top of foundation or any suitable X-Y plane. In this case the walls are assumed to be 10 feet high for the one storey cubes and 20 feet for the two storey cube.

2. Model the building as a series of cubes as shown in Figure E.6. The vertices are labeled for the first cube.
Step 4: Enter Cubé 1 using Absolute Coordinates.

By default the coordinates that are entered in the Support Data Entry Area are absolute coordinates. Absolute coordinates are measured from the coordinate origin. In the Support Data Entry Area, the cell highlighted in blue is active and ready to accept data.

1. Have the cell for the X coordinate of vertex 1 highlighted and enter
   0 RETURN
   0 RETURN
   0 RETURN.

This entry was not really necessary since the default values are zero. This means that the Y coordinate of vertex 1 is set.

2. Enter the X and Y coordinates for vertex 2 as
   19 ft 6 in 0/16 and 0 ft 0 in 0/16.

3. The X values for vertex 2 and 3 are the same so to increase the speed of data entry the value of vertex 2 will be copied to vertex 3.

Move to the X coordinate of Vertex 2 and press "C" to activate the COPY function. This cell now can be copied to any other.

Move to the destination cell (X coordinate of Vertex 3) and press "C" again. The data has been copied to this cell.

Enter the Y coordinate for vertex 3 as
   21 ft 4 in 0/16.

4. Enter the X and Y coordinates for Vertex 4 as
   0 ft 0 in 0/16 and 21 ft 4 in 0/16.

5. Enter the Z coordinates for Cube 1. Move to any cell in the Z column and enter
   10 ft 0 in 0/16.

Press "C" and then "A" to copy the value to all cells in this column.

Figure E.7 shows the results of the above actions.
6. Select the NEXT option to set this cube. The cube is drawn with a green base and verticals and blue top plates. Then the drawing window is automatically scaled to have the cube displayed at the largest possible scale. The top line of the screen indicates that Cube 2 now can be entered.
Step 5: Enter Cube 2 by Relative Coordinates. The Relative option.

Relative coordinates are coordinates measured from an existing vertex. In this case Cube 2 will be defined relative to the third vertex of Cube 1.

1. Select the RELATIVE option on the Support Menu. The first vertex on Cube 1 is marked by an X. Press UP ARROW twice to mark the third vertex. (At this time pressing ESCAPE will cancel the Relative option or pressing RETURN will fix the marked vertex as the relative origin.) Press RETURN to fix the vertex as the relative origin. The coordinate values that are now entered will be measured from this vertex.

2. Enter the following values into the Support Data Entry Area:

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Ft</td>
<td>0 in</td>
<td>0/16</td>
</tr>
<tr>
<td>10 Ft</td>
<td>0 in</td>
<td>0/16</td>
</tr>
<tr>
<td>10 Ft</td>
<td>0 in</td>
<td>0/16</td>
</tr>
<tr>
<td>0 Ft</td>
<td>0 in</td>
<td>0/16</td>
</tr>
</tbody>
</table>

Remember to use the Copy option when ever possible to increase the speed of data entry.

3. Select the NEXT option to set the cube allowing the next cube to be entered.

The cube is drawn and then the drawing window is automatically scaled to have the total structure within the drawing window.

NOTE: The absolute coordinates for Cube 2 are:

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>19 Ft</td>
<td>6 in</td>
<td>0/16</td>
</tr>
<tr>
<td>29 Ft</td>
<td>6 in</td>
<td>0/16</td>
</tr>
<tr>
<td>29 Ft</td>
<td>6 in</td>
<td>0/16</td>
</tr>
<tr>
<td>19 Ft</td>
<td>6 in</td>
<td>0/16</td>
</tr>
</tbody>
</table>
Step 6: Enter Cube 3 by Relative Coordinates and using the Box option.

The cubes produced by TrussCAD must have sides parallel to the X and Y axes and top plates at a constant Z value. With this information the X and Y coordinates of vertex 1 and 3 and the Z coordinate of Vertex 3 are the only data necessary for TrussCAD to calculate the other vertex coordinates. This is the basis for the Box option. This mode of input decreases the time of data entry.

1. Select the RELATIVE option and press DOWN ARROW. This causes Vertex 1 of Cube 2 to be marked. Mark the second vertex of Cube 2 by pressing the UP ARROW and then press RETURN.

2. Select the BOX option and on lines two and three a prompt for the X and Y coordinates for Vertex 1 is displayed. Enter
0 Ft 0 in 0/16 -16 Ft 0 in 0/16.

3. A prompt for the X, Y, and Z coordinates for Vertex 3 is displayed on lines two and three. Enter
25 Ft 8 in 0/16 14 Ft 6 in 0/16 20 Ft 0 in 0/16

The entry of Cube 3 supports is now complete. There is no need to select the Next option when using the Box input mode.

While entering the data for the Box option ESCAPE may be pressed if an error in data entry has occurred. This will cancel the entered values.

Step 7: Enter Cube 4.

1. Select the RELATIVE option and mark Vertex 2 of Cube 3 as the Relative origin.

2. Select the BOX option and enter
Vertex 1
X
0 Ft 0 in 0/16 5 Ft 2 in 0/16

and
Vertex 3
X
15 Ft 0 in 0/16 21 Ft 2 in 0/16 10 Ft 0 in 0/16

The Y coordinate of Vertex 3 should be, 20 ft 2 in 0/16. This will be corrected in Step 9.
Step 8: Check the Coordinates of each cube. The Edit option.

After all the support data has been entered it is good practice to review the coordinates of each cube to ensure there were no errors while typing the data or any calculation mistakes.

1. Select the EDIT option and the Edit Menu is displayed. The first cube’s top plates are highlighted in red and the coordinates of this cube are displayed in the Support Data Entry Area.

2. Select the NEXT_CUBE option to highlight the next cube and examine its coordinates. The absolute coordinates are displayed in the Support Data Entry Area.

3. When Cube 4 is viewed the mistake made in Step 7 is seen.

Step 9: Delete Cube 4.

1. With Cube 4 highlighted press RETURN to set the cube. Press "D" to delete the cube. The cube is deleted and the Support Menu is displayed again.

2. Input Cube 4 correctly.

Figure E.8 shows how the display appears after Step 9 is completed.
Step 10: Saving the support data. The Finished option.

1. Select the **FINISHED** option and respond to the prompt, 'Do you wish to save these supports [y/n]', by typing "Y".

2. Respond to the prompt, 'Do you wish to continue editing these supports [y/n]', by typing "N".

The screen is erased and the Main Menu is displayed.

If you wish to stop now and continue the tutorial at a later time select the Exit option. When returning to the tutorial activate the file, trial1.hse, and proceed with Step 11.

Step 11: Enter the roof data. The Roof option.

1. Select the **ROOF** option on the Main Menu. The Roof Menu is displayed along with the Roof Data Entry Area. The supports are drawn on the lower part of the screen with each vertex labeled numerically. The top plates of the first cube are highlighted in red.

2. Select the **LABEL** option and the labels on all cubes are erased except ones on the highlighted cube. This gives a clearer and less confusing display.

Screen Layout

Line 1: The setbacks and truss spacing in inches for the highlighted cube are displayed at the center of the line.

Line 4: This line contains the headings for the five columns that make up the Roof Data Entry Area. The first column identifies the cube side that each row pertains to. The sides are defined using the cube vertex labels. The following columns are used to input the pitch, heel height, overhang and cantilever of each side.

Line 5 to 8: This is the Roof Data Entry Area and movement in this area is through the arrow keys. The area is broken down into sixteen cells.

The remaining part of the screen is the drawing window.
Step 12: Enter roof data for Cube 1

1. Use the NEXT_CUBE option to highlight the first cube if necessary. It is defined by vertices 1 through 4. Press RETURN and now the roof data for the cube can be entered.

2. The truss span direction is prompted for first. UP ARROW is used to change the span from the X to Y direction or vice versa. The span direction is shown graphically by a red arrow on the cube. Have the span in the X direction and press RETURN. The span direction is now set.

3. Highlight any cell in the Pitch column by using the arrow keys. Enter, 4 RETURN.

4. Select the COPY option and the first cell will be copied. This option is the same as the one in the Support Menu. Press "A" for a column copy and all pitches are set to 4.0000/12.

5. Highlight any cell in the heel height column and enter, 4 RETURN. If the heel height is entered as an integer number it is interpreted as being a nominal heel height. For any other case the heel height will be considered to be the actual height. Copy this value to the entire column.

6. Highlight any cell in the Overhang column and enter 24 RETURN. Copy this to the entire column.

7. The cantilever values will be left at their default value of zero. The setback and spacing of the trusses will also be left at their default values.

8. The roof data is complete for Cube 1. Select the NEXT option to have the roof drawn and the next cube highlighted.

Figure E.9 shows the data entered into the Roof Data Entry Area. Figure E.10 shows the results of selecting the Next option.
Step 13: Enter roof data for Cube 2

Gable ends in TrussCAD are designated by a pitch of zero. Sides 6-7 and 8-5 are gable ends.

1. Have the second cube highlighted, it is defined by vertices 5 through 8, and press RETURN. Cube 2 roof data can now be entered.

2. Set the truss span in the Y direction.

3. Enter a pitch of 4 for sides 5-6 and 7-8.

4. Enter a heel height of 4 for sides 5-6 and 7-8.

5. Enter an overhang of 24 for sides 5-6 and 7-8.

6. Select the NEXT option to move on to the next cube.

Since side 6-7 and 8-5 are gable ends the setback values will be ignored when the trusses are placed on the cube.
Step 14: Enter roof data for Cube 3.

1. The truss span for Cube 3 is in the X direction and the roof data is

   4.0000/12  4 in  24.0000 in  0.0000 in
   4.0000/12  4 in  24.0000 in  0.0000 in
   4.0000/12  4 in  24.0000 in  0.0000 in
   4.0000/12  4 in  24.0000 in  0.0000 in

2. Before selecting the Next option change the setbacks and truss spacing on Cube 3. Select the SETBACK option and enter in a value of 50 for setback1 and 40 for setback2.

3. Select the SPACING option and enter a value of 16 for the truss spacing.

4. Select the NEXT option and the roof on Cube 3 is drawn. The units of the setbacks and spacing are inches.

Step 15: Enter roof data for Cube 4.

1. The truss span for Cube 4 is in the Y direction and the roof data is

   4.0000/12  4 in  24.0000 in  0.0000 in
   4.0000/12  4 in  24.0000 in  0.0000 in
   4.0000/12  4 in  24.0000 in  0.0000 in
   0.0000/12  4 in  24.0000 in  0.0000 in

Note the pitch value for the fourth side is zero.

2. Change the setbacks to 48 inches and the spacing to 24 inches.

3. Select the NEXT option.

Figure E.11 shows the cubes with all the roofs drawn.
Step 16: Join the roofs and generate truss profiles. The Combine option.

The Combine option is only used when all the roofs have been entered. It performs two major tasks. The first is to find the intersections of adjacent roofs and the second is to place trusses and generate truss profiles. The 'combining' of a building may take ten to twenty seconds to complete so please be patient.

1. Select the COMBINE option. The roofs are joined and the bottom chord of each truss is drawn on the building.

Figure E.12 shows the results of the Combine option.

Step 17: Defining interior bearing. The Ibearing option.

The Ibearing option allows one or two interior bearings to be defined on each truss. Trusses 1, 2, 7 and 8 have interior bearing. The location of the interior bearing is common to the four trusses.

1. Select the IBEARING option and the screen is redrawn with the top view and the Selection Menu displayed. The first truss is displayed in yellow with its truss number and group in the upper right corner of the display.

2. Select the SINGLES option. With truss 1 displayed in yellow press RETURN to select it. Press RETURN again to select truss 2. Use the NEXT option to display truss 7 in yellow then press RETURN twice to select trusses 7 and 8. Choose the DONE option to terminate the selection process.

3. Press "y" in response to the prompt, 'Are the trusses selected correctly [y/n]'. Press "N" in response to the prompt, 'Delete the existing interior supports [y/n]'. The drawing window is redrawn with truss 1A displayed and its left support marked by a yellow 'X'.

4. Enter a value of, 5 ft 0 in 0/16, for the distance from the marked supported to the first interior support. The support is drawn along with a dimension from the left support.

5. Enter a value of, 10 ft 0 in 0/16, for the distance from the marked support to the second interior support. The support is drawn along with a dimension from the first interior support.
6. Respond to the prompt, 'Are the supports correct [y/n]', by typing a "y". The trusses are regrouped and the top view is displayed again. Press the ESCAPE option and the Roof Menu reappears.

If there is only one interior support on a truss enter zeros for the location of the second support.

---

Step 18: Viewing the building and the truss profiles. The Display Menu.

The Display option leads to the Display Menu. The Display Menu gives control over the orientation of the building in the drawing window.

1. Select the DISPLAY option and the Display Menu appears and the Roof Data Entry Area is erased.

---

Step 19: The top view of the building. The Top option.

1. Select the TOP option and the drawing window is erased and the top view of the building is drawn. It will not be centered or scaled properly in the window.

2. Select the ASCALE (auto-scale) option and the view is automatically translated to the center of the drawing window and scaled to have the largest possible drawing.

The Top option produces one of the four assigned views provided by TrussCAD. The others are Front (front view), Rside (right side view) and Iso (isometric view). Try to display the other views now. The Ascale option will have to be used to center each view. The orientation of the axes on the screen for each view are shown in Figure E.13.

Figures E.14 and E.15 are the top and front views of the building.
Step 20: Defining a new view. The Udefine option.

The Udefine option lets the operator define rotations about the three principle axes. The rotations are accumulative. Have the top view displayed and auto-scaled.

1. Select the UDEFINE option and a prompt requesting the rotation about the X axis is displayed.
   Enter 0 RETURN.
   Enter 0 RETURN for the Y rotation.
   Enter -45 RETURN for the Z rotation.

The screen is redrawn and the top view has been rotated 45 degrees in a clockwise direction. The sign convention for rotation angles follow the right hand rule.

Go ahead and try some different rotations now.

Step 21: Displaying a section of the building on the drawing window. The Zoom option.

The Zoom option allows the operator to define a rectangular area or zoom window and this area is scaled and translated to take up the entire drawing window. Have the top view displayed and auto-scaled.

1. Select the ZOOM option and a white cursor appears at the center of the drawing window. Use the arrow keys to move it left of and above Cube 1. Press RETURN and the first corner of the zoom window is set. Move the cursor right of and below Cube 1 and press RETURN. A white rectangle should have been drawn as the cursor was moved. The contents of the zoom window are drawn to occupy the entire drawing window.

You may return to the original display by selecting the Ascale option or further zooming is possible on the current display.

The Page Up and Page Down keys increase or decrease the cursor jump size when defining the zoom window.
Step 22: Translating the building on the drawing window. The Pan option.

The Pan option allows the operator to translate the building on the drawing window without changing the scale. Have the top view displayed and auto-scaled.

1. Select the PAN option and a white cursor appears at the center of the drawing window.

2. Use the arrow keys to position the cursor on one of the roof peaks of Cube 1. You may have to use the Page Up and Down keys to achieve this. Press RETURN and the screen is redrawn with the peak of Cube 1 at the center of the drawing window.

Step 23: Viewing the truss profiles. The Vtruss option.

The Vtruss option allows the operator to highlight any truss and view its fully dimensioned profile.

1. Select the VTRUSS option and the screen is redrawn with the top view displayed. The first truss on Cube 1 is highlighted in yellow.

On line one of the screen the truss spacing, truss number and group are displayed. The truss spacing is given in inches. The first number is the distance from the previous truss to the highlighted one. In this case it is the setback for Truss 1. The second number is the spacing from the highlighted truss to the next truss. In this case the distance between Truss 1 and 2. The trusses are numbered sequentially and given a group letter. The group letter identifies trusses having the same profile and support conditions. Also girders in a step-down hip system are identified. In this case the highlighted truss is truss number 1 and belongs to group A.
Step 24: Highlighting a truss and viewing the profile.

1. Select the NEXT option until truss number 7 is highlighted and press RETURN. The profile appears with dimensions on all points that are needed to uniquely define the truss.

2. Press RETURN and the truss is erased and the top view reappears with truss number 8 highlighted. Go ahead and highlight any truss and view the profile.

3. When finished viewing the trusses select ESCAPE and the Display Menu appears. Select ESCAPE again and the Roof Menu appears.

Figure E.16 is the profile of truss number 7.

Step 25: Saving roof data and truss profiles. The Finished option.

1. Select the FINISHED option and respond to the prompt, 'Do you wish to save these roofs [y/n]' by typing "y". The roof data is saved to the file trial1.hse and the truss profile data to trial1.tru.

2. Press "N" in response to the prompt, 'Do you wish to continue editing the roofs [y/n]'. The screen is cleared and the Main Menu is displayed.

Step 26: Plotting views and truss profiles. The Drwg (Drawing) option.

1. Select the DRWG option and the Drawing Menu is displayed. To plot a particular view or truss profile it must be displayed on the drawing window. Changing the view is achieved though the Display option.
Step 27: Setting the drawing window for plotting. The Display option.

1. Select the DISPLAY option and the Display Menu is shown. It is similar to the one used during roof input.

2. Select the TOP option followed by the ASCALE option. The top view of the building is displayed. Select ESCAPE to set the drawing window and the Drawing Menu reappears.

3. Select the PLOT option to plot the contents of the drawing window. Press "P" in response to the prompt, 'Send results to plotter or file [p/f]'. Press RETURN and the drawing window is plotted.

The top view when plotted has the trusses and cubes labeled. This plot is a truss layout plan.

The plotting routine expects the first four pen locations in the pen carousel to be occupied. The plotter should be connected to serial port 1.

The Level option in the Drawing Menu may be used to have different levels visible or invisible. TrussCAD groups lines that represent roofs, cube bases, cube verticals, top plates and trusses into separate levels. The Level option gives the operator control over the visibility of each level. Select the LEVEL option and shut off several levels and then display different views to see the results.

Try plotting other views now.

If the data is sent to a file, the file has a default extension of 'PLT'.

Figure E.17 is the top view plot of the building.
Step 28: Plotting a truss profile.

1. Select the DISPLAY option and then the VTRUSS option. The top view is displayed with the first truss highlighted.

2. Highlight truss number 7 by using the NEXT option and then press RETURN. The truss profile is drawn.

3. Select ESCAPE twice to return to the Drawing Menu. Select the PLOT option and send the results to the plotter. Plot any other truss profiles in the same way.

Figure E.18 is the truss profile plot of truss number 7.

Step 29: Plotting is completed. The Finished option.

1. Select the FINISHED option on the Drawing Menu and the screen is erased and the Main Menu is displayed.
Step 30: Printing a report on truss profiles. The Print option.

The Print option produces a report on the different truss groups. It gives the quantity, span, spacing, pitches, cantilevers, overhangs, and heel heights of each truss group. Also the setback of a girder truss is given and if there is interior bearing it is noted.

1. Select the PRINT option and press "P" in response to the prompt, 'Send results to printer or file [p/f]'. The report is sent to the printer.

The printer should be connected to parallel port 1.

If the data is sent to a file, the file has a default extension of 'TEX'.

Figure E.19 is the report produced for this building.
Step 31: Generate the flat trusses for the building.

To place flat trusses on this building copy the file, trial1.hse, to a new file, trialaf.hse. Edited this new file to generate the flat trusses.

1. Select the FILE option and then the CLOSE option to close file trial1.hse.

2. Highlight the file name, trial1.hse, using the arrow keys and then select the COPY option. Press RETURN in response to the first prompt. Type in the file name, "trialaf.hse" in response to the prompt, 'Copy to '.

3. Activate file trialaf.hse.

4. Select the ROOF option to edit the roof. Using the NEXT_CUBE option highlight the cube that is to have its roof data changed and then press RETURN. The roof data for the cube now can be edited. Flat truss profiles are generated if the pitches on a cube are all zero. The heel height entries are the depths of the flat trusses.

5. Viewing, plotting and printing are done as before.
Figure D.1: Labeling Convention for Cube Vertices

Figure D.2: Definition of Setback
Figure D.4: Top View of the Two Storey Building
Figure D.5: Orientation of Axis on the Drawing Window
Figure D.6: Placement of Axes on the Building
Figure D.7: Entry of Support Data for Cube 1

Figure D.8: The Supports for the Building
Figure D.9: Roof Data for Cube 1

Figure D.10: Roof on Cube 1
Figure D.11: The Roofs on All Cubes

Figure D.12: After the Combine Option
Figure D.13: Orientations of Axes for the Given Views
Figure D.16: Profile of Truss Number 7
### GROUP A

<table>
<thead>
<tr>
<th>Girdel setback (in)</th>
<th>Quantity</th>
<th>Spacing (in)</th>
<th>Span 19 ft 6 in 0 16th</th>
</tr>
</thead>
<tbody>
<tr>
<td>48.00</td>
<td>2</td>
<td>24.00</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interior Bearing</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>4.00/12</td>
<td>4.00/12</td>
</tr>
<tr>
<td>Heel height</td>
<td>3.94in</td>
<td>3.94in</td>
</tr>
<tr>
<td>Overhang</td>
<td>24.00in</td>
<td>24.00in</td>
</tr>
<tr>
<td>Cantilever</td>
<td>.00in</td>
<td>.00in</td>
</tr>
</tbody>
</table>

### GROUP B

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>Quantity</th>
<th>Span 19 ft 6 in 0 16th</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.00</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interior Bearing</th>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>4.00/12</td>
<td>4.00/12</td>
</tr>
<tr>
<td>Heel height</td>
<td>3.94in</td>
<td>3.94in</td>
</tr>
<tr>
<td>Overhang</td>
<td>24.00in</td>
<td>24.00in</td>
</tr>
<tr>
<td>Cantilever</td>
<td>.00in</td>
<td>.00in</td>
</tr>
</tbody>
</table>

### GROUP C

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>Quantity</th>
<th>Span 19 ft 6 in 0 16th</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.00</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>4.00/12</td>
</tr>
<tr>
<td>Heel height</td>
<td>3.94in</td>
</tr>
<tr>
<td>Overhang</td>
<td>24.00in</td>
</tr>
<tr>
<td>Cantilever</td>
<td>.00in</td>
</tr>
</tbody>
</table>

### GROUP D

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>Quantity</th>
<th>Span 19 ft 6 in 0 16th</th>
</tr>
</thead>
<tbody>
<tr>
<td>24.00</td>
<td>2</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Left</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
<td>4.00/12</td>
</tr>
<tr>
<td>Heel height</td>
<td>3.94in</td>
</tr>
<tr>
<td>Overhang</td>
<td>24.00in</td>
</tr>
<tr>
<td>Cantilever</td>
<td>.00in</td>
</tr>
</tbody>
</table>

---

*Figure D.19: TrussCAD Report*
TRUSSCAD

Operator: Tom
Description: Cornwall File No 12345 Job No 54321
Date: n 11 d  4 y 1988

**GROUP E**

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>24.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>6</td>
</tr>
</tbody>
</table>

Span 10 ft 0 in 0 16th.

<table>
<thead>
<tr>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
</tr>
<tr>
<td>Heel height</td>
</tr>
<tr>
<td>Overhang</td>
</tr>
<tr>
<td>Cantilever</td>
</tr>
</tbody>
</table>

**GROUP F**

<table>
<thead>
<tr>
<th>Girder setback (in)</th>
<th>50.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>1</td>
</tr>
</tbody>
</table>

Spacing (in)= 16.00

<table>
<thead>
<tr>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
</tr>
<tr>
<td>Heel height</td>
</tr>
<tr>
<td>Overhang</td>
</tr>
<tr>
<td>Cantilever</td>
</tr>
</tbody>
</table>

**GROUP G**

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>16.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>1</td>
</tr>
</tbody>
</table>

Span 25 ft 8 in 0 16th.

<table>
<thead>
<tr>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
</tr>
<tr>
<td>Heel height</td>
</tr>
<tr>
<td>Overhang</td>
</tr>
<tr>
<td>Cantilever</td>
</tr>
</tbody>
</table>

**GROUP H**

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>16.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>1</td>
</tr>
</tbody>
</table>

Span 25 ft 8 in 0 16th.

<table>
<thead>
<tr>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pitch</td>
</tr>
<tr>
<td>Heel height</td>
</tr>
<tr>
<td>Overhang</td>
</tr>
<tr>
<td>Cantilever</td>
</tr>
</tbody>
</table>

Figure D.19: TrussCAD Report (Continued)
| GROUP I |
| Spacing (in): 16.00 |
| Quantity: 1 |
| Left Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |
| Right Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |

| GROUP J |
| Spacing (in): 16.00 |
| Quantity: 1 |
| Left Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |
| Right Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |

| GROUP K |
| Spacing (in): 16.00 |
| Quantity: 1 |
| Left Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |
| Right Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |

| GROUP L |
| Spacing (in): 16.00 |
| Quantity: 1 |
| Left Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |
| Right Pitch: 4.00/12 |
| Heel height: 3.94in |
| Overhang: 24.00in |
| Cantilever: .00in |

Figure D.19: TrussCAD Report (Continued)
GROUP M

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>16.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>5</td>
</tr>
<tr>
<td>Span 25 ft 8 in</td>
<td>0 16th</td>
</tr>
</tbody>
</table>

Left
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

Right
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

GROUP N

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>16.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>1</td>
</tr>
<tr>
<td>Span 25 ft 8 in</td>
<td>0 16th</td>
</tr>
</tbody>
</table>

Left
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

Right
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

GROUP O

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>16.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>1</td>
</tr>
<tr>
<td>Span 25 ft 8 in</td>
<td>0 16th</td>
</tr>
</tbody>
</table>

Left
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

Right
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

GROUP P

<table>
<thead>
<tr>
<th>Spacing (in)</th>
<th>16.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quantity</td>
<td>1</td>
</tr>
<tr>
<td>Span 25 ft 8 in</td>
<td>0 16th</td>
</tr>
</tbody>
</table>

Left
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

Right
- Pitch: 4.00/12
- Heel height: 3.94in
- Overhang: 24.00in
- Cantilever: .00in

Figure D.19: TrussCAD Report (Continued)
Figure D.19: TrussCAD Report (Continued)
TRUSSCAD

Operator: Tom
Description: Cornwall File No. 12345 Job No. 54321
Date: 11th January 1980

GROUP C

Girder setback (in)= 40.00 Quantity= 1
Spacing (in)= 16.00 Span 25 ft 8 in 0 16th

Left
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

Right
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

GROUP V

Spacing (in)= 24.00 Quantity= 5
Quantity= 5 Span 15 ft 0 in 0 16th

Left
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

Right
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

GROUP W

Spacing (in)= 24.00 Quantity= 1
Quantity= 1 Span 15 ft 0 in 0 16th

Left
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

Right
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

GROUP X

Girder setback (in)= 48.00 Quantity= 1
Spacing (in)= 24.00 Span 15 ft 0 in 0 16th

Left
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

Right
Pitch 4.00/12
Heel height 3.94
Overhang 24.00
Cantilever .00

Figure D.19: TrussCAD Report (Continued)
APPENDIX E

DATA STORAGE
House File Structure.

The file is an ASCII formatted direct access file. The record length is 40 characters.

<table>
<thead>
<tr>
<th>Record Number</th>
<th>Description</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>House description</td>
<td>(A40)</td>
</tr>
<tr>
<td>2</td>
<td>Operator's name</td>
<td>(A40)</td>
</tr>
<tr>
<td>3</td>
<td>Date</td>
<td>('m',I2,'d',I2,'y',I4)</td>
</tr>
<tr>
<td>4</td>
<td>Time</td>
<td>('time',I2,':',I2)</td>
</tr>
<tr>
<td>5</td>
<td>First Cube</td>
<td></td>
</tr>
<tr>
<td></td>
<td>X, Y, Z coordinates of the first vertex, ident, number of cube sides</td>
<td>(3I10,A5,I5)</td>
</tr>
<tr>
<td>6, 7, 8</td>
<td>X, Y, Z coordinates of the second, third and fourth vertex, ident</td>
<td>(3I10,A5)</td>
</tr>
<tr>
<td>9</td>
<td>Truss spacing, setback 1 and 2, roof style, ts and truss direction</td>
<td>(3F10.4,2A3,A4)</td>
</tr>
<tr>
<td>10, 11, 12, 13</td>
<td>Pitch, heel height, cantilever and overhang for side 1, 2, 3 and 4</td>
<td>(4F10.4)</td>
</tr>
<tr>
<td>14</td>
<td>Second Cube</td>
<td></td>
</tr>
<tr>
<td></td>
<td>End of data marker 'n!@#'</td>
<td>(A40)</td>
</tr>
</tbody>
</table>

The variables, ident and ts, are not currently used. They are to be used for storing the width of bearing walls and the style of trusses on a cube.
Truss File Structure

The file is an ASCII formatted direct access file. The record length is 51 characters.
The points saved for each truss profile are shown in Figure E.1.

<table>
<thead>
<tr>
<th>Record Number</th>
<th>Description</th>
<th>Format</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total number of trusses</td>
<td>(I5)</td>
</tr>
<tr>
<td>2</td>
<td>Number of trusses on first cube</td>
<td>(I5)</td>
</tr>
<tr>
<td>3</td>
<td>Number of trusses on second cube</td>
<td>(I5)</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Number of trusses on last cube</td>
<td>(I5)</td>
</tr>
<tr>
<td>(J+1)</td>
<td>First Truss</td>
<td></td>
</tr>
<tr>
<td>(J+2) to (J+9)</td>
<td>Group label, girder set back and truss spacing</td>
<td>(I5,2I10)</td>
</tr>
<tr>
<td></td>
<td>X, Y, Z coordinates of point 1 to 8 of the first truss</td>
<td>(3E17.10)</td>
</tr>
<tr>
<td>(J+10)</td>
<td>Second Truss</td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Last</td>
<td>[EOF]</td>
<td></td>
</tr>
</tbody>
</table>
The value of Point 6 for the case of a triangular truss is zero.

Figure E.1: Truss Data Points
REFERENCES


VITA AUCTORIS

THOMAS L. DEBEVC

1963


1982

In June, graduated with the Ontario Secondary School Honorary Graduation Diploma from Riverside Secondary School Windsor, Ontario.

In September, admitted to the Faculty of Engineering at the University of Windsor to pursue the Bachelor of Applied Science.

1986

In April, graduated with the Bachelor of Applied Science in Civil Engineering from the University of Windsor.

In September, admitted to the Faculty of Graduate Studies and Research in the University of Windsor to pursue the Master in Applied Science.

Joined the Department of Civil Engineering, University of Windsor, as a Research and Teaching Assistant.