

# Designing Virtual Tours of 3D-Adaptative Greenhouses

A.M. Espínola<sup>1</sup>, G.F. Parra<sup>1</sup>, L. Iribarne<sup>1</sup> and J.A. Torres<sup>2</sup>

<sup>1</sup> Unit of Engineering in Graphical Computation, University of Almería, Spain

<sup>2</sup> Group of Computer Science and Environment, University of Almería, Spain

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## Abstract

*This work concerns the application of graphical computer knowledge into another important discipline in the south-east of Spain: the agriculture. In this work we cover an almost unexplored area in the agriculture environment: the design of three-dimensional greenhouses virtual tours. This paper presents a 3D-software tool for building greenhouse structures adapted to certain land form, and visualizing these structures with total freedom of movement. In order to obtain it, we have used several algorithms on space and vectorial geometry, matrix algebra transformations, graphical computer techniques and existing 3D technologies.*

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications

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## 1. Introduction

The adoption of greenhouses in parts of south-east of Spain has revolutionized the industry and economy of the area. As it occurs in any engineering discipline, technological advances contribute towards guaranteeing and improving the quality of the processes and products developed within a framework of standards or norms. Specific fields of application of computer-aided techniques in engineering are found mainly in systems modelling. Examples include the modelling of biological systems on a small, medium or large scale (such as in genetics, plants or ecosystems), social systems (simulation of behaviour within social groups or market analysis) and industrial systems comprising multiple stages and products (simulation of aircraft, modelling of structures and ‘mass customization’). In the present case, we have applied it to the 3D-visualization of structures for the construction of tunnel greenhouses.

Modelling of greenhouse systems with computer-assisted techniques is not a novel idea, given the complementary character that computing has assumed for engineering in general. In our particular case, previous studies simulated the effect of a multitunnel greenhouse as a captor of energy. We used finite element calculations to analyze the amount of radiation striking the external surfaces of the greenhouse and penetrating on the inside as well. However, these studies did not provide the development of 3D design and visualization of commercial greenhouse.

In this work we present a singular greenhouse modelling software developed to reach two main targets: (a) on the one hand to design three-dimensional greenhouses by means of a simple graphical interface, and (b) on the other hand to create a virtual tour of the structure previously created. The type of greenhouse used in the design is the called ‘modular multitunnel’, widely used by agriculture thanks to the enormous advantages of the canopy production. The application of this software is obvious: the user can design and visualize a virtual greenhouse from all the possible perspectives before its real construction.

A multitunnel greenhouse is typically built using a modular building structure with several semi-cylindrical arched roofs. The structure is made of steel and plastic, used as cladding. The building of this type of greenhouse is increasingly common because of the advantages it confers over other types. It is more hermetic, which means that the microclimate within the greenhouse can be better controlled; the curved roof provides better spreading of light inside the greenhouse, and wide distance between the posts makes movement of machinery in and out easier and lets the installation of zenithal ventilation at the leeward end.

## 2. The 3D-greenhouse software tool

In order to design the 3D greenhouses we have created a graphical interface formed by one rectangular structure (i.e., ‘plane’) and divided in small rectangles (i.e., ‘grids’), which

corresponds with a top-view of the land to hibernate. These grids share vertices and edges with their adjacent neighbours (see Figure 2).

The user (i.e., the greenhouse designer) can select the vertices of the grids on the plane and create a polygon that delimits the form of the 3D greenhouse. The software does not allow the overlapping of polygon lines, since the result would be an impossible greenhouse.

Later, in order to create the greenhouse in three dimensions, a set of basic 3D modules, previously constructed in Autocad, are used to form the complete structure. Once designed the 3D greenhouse, our software allows the user to visit it following a virtual tour. To make it possible, we have created a 3D engine that includes most important 3D graphical engines characteristics: horizontal and vertical movement of the camera as well as rotation, and collision detection to maintain the distance with the polygons of the walls and with the ground.

In the next sections we will study the 3D greenhouses design and virtual tours of separated way, deepening in the most important problems of each objective, and finally we will show the obtained results and possible improvements.

### 3. Greenhouses design

In order to create a greenhouse adapted to the form of the polygon, we have used some small basic 3D modules fitted like a puzzle when building the complete structure. These basic modules are formed by the ceiling (with form of arc), the pillars and the rest of the attachment elements. Figure 1 shows the basic 3D module. Each grid of the plane will correspond with a complete basic module. The complete greenhouse design will be then formed by an adjacent group of grids (i.e., of basic 3D modules).

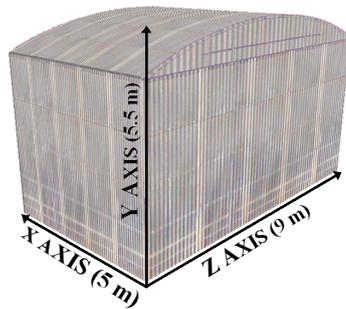


Figure 1: Basic 3D module measures.

#### 3.1. Regular greenhouses

Allowed types of greenhouses are: regular and irregular. ‘Regular greenhouses’ are those formed only by complete grids. Figure 2 shows an example. Our software calculates

this kind of greenhouse (regular form) from the polygon, starting to draw up lines (by using the Bresenham algorithm) through the middle of the grids, and from left to right of the plane. The software controls whether a straight line of the polygon is detected. In this way, all the grids located at the right side of a straight line with odd number belong to the polygon, and those ones located at the right side of a straight line with even number, do not comprise of the polygon introduced by the user.

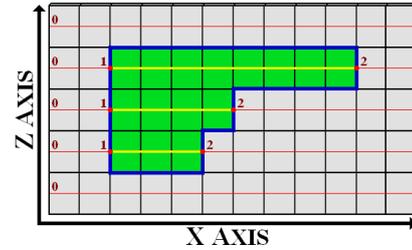


Figure 2: Regular greenhouse example. This is the detection method used to find complete grids.

Once calculated the grids of the greenhouse, this structure is surrounded with walls and all necessary 3D elements are included to complete the greenhouse.

#### 3.2. Irregular greenhouses

A singular problem appears with ‘irregular greenhouses’ (see Figure 3).

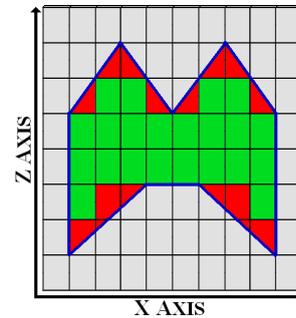
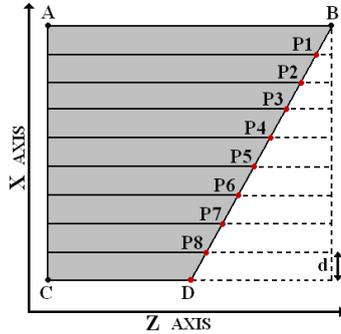


Figure 3: Irregular greenhouse example. The red zones are the greenhouse incomplete grids (the result is in Figure 5).

In this case the greenhouse is also formed by incomplete grids, that is, irregular basic modules. Therefore we must adapt a generic 3D basic module to the user polygon. In the first place, we obtain the four points that delimit the incomplete grids. In many cases these grids present triangular form, so two points are overlapped. These four points are the A, B, C and D points showed in Figure 4. This figure shows an example of a greenhouse ceiling modification. With the objective of modifying the coordinate Z of some object vertices, we draw up a line from the point A to C, and another

one from B to D. When a distance 'd' is reached throughout the X axis (the distance between each polygon of the ceiling of the greenhouse) we have a new vertex of the 3D object to modify, and so on. This technique is applied to all the basic 3D objects.



**Figure 4:** The Z coordinate of each red point must be modified to create the irregular ceiling.

#### 4. Virtual tour

The 3D-greenhouse tool uses an additional module to create virtual tours from a greenhouse previously designed. The 3D engine that supports the building of virtual tours has the following basic characteristics: camera rotation, movement through the virtual world, and collisions detection. In addition, the virtual tour is supported by a text console that can dynamically modify some surroundings properties.

##### 4.1. Camera rotation

The object rotation on one of the three coordinate axes is quite simple. It is only necessary to apply a rotation matrix with respect to the wished axis of coordinates. The problem appears when we want to make a rotation on an axis that does not correspond with one coordinates axis, that is, a rotation on an arbitrary axis [HB03]. In this case the wished rotation has several steps summarized in the following composition of matrix algebra transformations:

$$\begin{pmatrix} x' \\ y' \\ z' \\ 1 \end{pmatrix} = T^{-1}R_x^{-1}(\alpha)R_y^{-1}(\beta)R_z(\theta)R_y(\beta)R_x(\alpha)T \begin{pmatrix} x \\ y \\ z \\ 1 \end{pmatrix}$$

We use this composition in the two possible movements of the mouse: horizontal and vertical.

##### 4.2. Camera movement

For the camera movement through the 3D world, we need to know two fundamental data: the camera and the objective positions. Considering that the camera's horizontal movement occurs throughout the X and Z axes, and the vertical

throughout the Y axis, we can establish the different types of movement by using vectorial geometry [Bea05].

##### 4.3. Collisions detection

The collisions detection between the camera and the polygons of the scene has been implemented using space geometry [vdB03]. We have used the 'sphere-triangle' collision detection method.

##### 4.4. Text console

In addition, the user (designer) can modify some surroundings properties thanks to a text console incorporated into the virtual tour. The user must write the suitable order. The most important properties that can be changed are the followings:

- i. Modify the distance between the attachment pillars. Scale matrix is applied to the corresponding 3D meshes, since the visual effect is very good and the 3D objects form modification is inappreciable.
- ii. Change the greenhouse covers. The complete appearance of the 3D greenhouse aspect can be modified when selecting a cover type. The simulated cover types are: plastic and polycarbonate.
- iii. Open and close ventilation zenithal windows. The Y coordinates of some ceiling vertices are modified dynamically, and new 3D elements are added to the structure.
- iv. Show or hide plants. We use the textures alpha channel to alternate between plants or transparent textures.

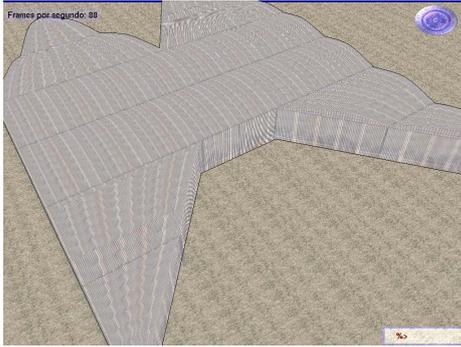
#### 5. Conclusions and future works

In this paper we present a 3D-software tool that creates a greenhouse adapted to certain land form, and it also allows observing this 3D structure with total freedom of movement. We have used several algorithms on space and vectorial geometry, matrix algebra transformations, graphical computer techniques and existing 3D technologies.

In Figures 5, 6 and 7 we show some graphical results of our 3D-software tool. In Figure 5 we show the result of modelling (in an outer perspective) an irregular greenhouse. Figure 6 shows a polycarbonate greenhouse with plants, and Figure 7 includes an example of a greenhouse with the zenithal windows opened.

Some of the advantages of the tool used in greenhouse design (in terms of time and costs) are the following:

- Visualization of the interior of the greenhouse including the lay-out of air-conditioning equipment, placement and size of irrigation sectors, as well as passageways and crop lines.
- The tool allows a better use of the ground surface of the plot, respecting design limitations such as orientation of



**Figure 5:** Irregular polycarbonate greenhouse created with the polygon of Figure 3.



**Figure 6:** Polycarbonate greenhouse with plants.

the long axis of the greenhouse, depending on the conditions of solar irradiation and dominant wind in the vicinity. For the same reason, it can be applied in any latitude since it permits the longitudinal orientation of the greenhouse to be oriented north-south (predominant case in Almería) as well as east-west.

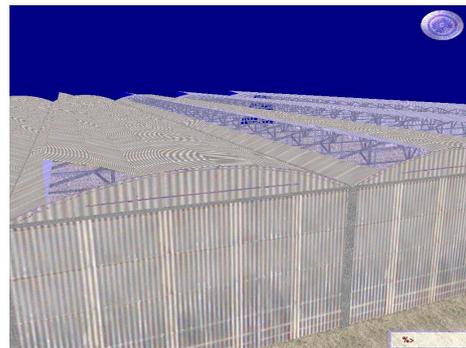
- Using this design tool, placement of the greenhouses, paths and auxiliary installations can be done to optimize the routing of products within the farm estate, which is particularly important for farms larger than 5 ha.
- Possibility of extending the 3D tool to greenhouses in which design parameters and calculations vary, such as the distance between pillars.
- It can be used in the pre-processing of calculations to improve the greenhouse structure.

The virtual tour visualization has been optimized by reducing the polygons of the scene using real photographs, which increases the life of the application. Some other improvements of the work are:

- i. Simulate the plant behaviour inside a virtual greenhouse, converting our 3D-software tool in an expert system. We have some experience in simulation of greenhouses [GIB\*98], [GIGB99].
- ii. Add more characteristics to the 3D engine, including representations of particle systems to simulate the land irrigated system water, as well as the simulation of 3D objects physical properties.
- iii. Introduce some guided virtual tours through user-defined trajectories, exporting this sequence to some video format for its later reproduction.

## 6. Acknowledgements

We are grateful to the Information Systems Group at the University of Almería by supporting this work.



**Figure 7:** Greenhouse with the ventilation zenithal windows opened.

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