Reverse Engineering Approach for Precise Measurement of the Physical Attributes Related to the Geometric Features of Agricultural Products

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ABSTRACT

The irregular shape of most agricultural products complicates their physical and engineering analysis. Therefore, precise description of the irregular product geometric surface form/shape is significant for any related analyses used in both product quality evaluation and design of agricultural machinery systems. This study describes a reverse engineering application procedure for precise description of the physical attributes related to geometric features (size, shape, volume etc.) of the agricultural products under consideration. In the study, a three-dimensional (3D) laser scanner has been utilised and 3D digital model data of the selected sample agricultural product (Pecan Fruit) processed in the virtual environment through 3D scanner software and 3D parametric solid modelling design software has been collected. After 3D solid models were created, some of the physical attributes related to geometric features of the agricultural products were measured precisely and realistic virtual 3D computer aided design (CAD) data was provided for deeper rheological investigation such as structural deformation, fluid dynamics (flow) and heat transfer analyses of the products by means of computer aided engineering (CAE) techniques. Finally, a comparative deformation simulation case study was concluded. This study contributes to further research into the development of agricultural machinery and equipment through the utilisation of reverse engineering and CAD tools.

KEYWORDS: Reverse Engineering, Design of Agricultural Machinery, Computer Aided Design, Computer Aided Engineering, Rheological Analysis, Organic Materials, Pecan Fruit

1. INTRODUCTION

A description of agricultural product shape is often necessary in research fields for a variety of different purposes [1]. One of the most important research areas for agricultural products as biological materials is determining physical attributes related to geometric features such as size, surface area, shape, volume etc. These features are important physical attributes which are used in screening, grading, and quality control of the agricultural products. The geometry is vitally significant in rheological investigations such as structural deformation, flow and heat/mass transfer analyses and their aerodynamic and hydrodynamic behaviour investigations.

Rheology is the science that studies the structural deformation of materials including flow. Rheological data are required in product quality evaluation, engineering calculations, and process design [2]. The design and development of agricultural/food machinery systems are also related to these type of properties of agricultural biological and/or organic material directly or indirectly. Hence, it is very important to conduct research considering the properties of these materials, such as fruit and vegetables [3]. In the rheological investigation of the organic materials, one of the difficulties arise because of their heterogeneous inner structures and irregular shapes. Hence, their physical and engineering analyses may become more complicated.

Difficulties related to irregular product geometry have been considered by simplifying product geometry from irregular features to fully perfect rectangular, elliptical, cylindrical or spherical geometric shapes in engineering analysis and/or mathematical calculations. Some of the studies related to rheological analysis of the agricultural materials consisting of simplified geometry are sampled in Figure 1 [4-9].

(Figure 1. Geometry simplification examples in engineering analysis of agricultural products)

In addition to these studies which include simplified geometry, advances in reverse engineering (RE) technology and related applications have helped researchers in rheological analyses of organic materials using advanced reverse engineering tools to obtain original digital CAD models of the organic materials with their complex surface forms, however, the number of these types of studies are very limited. Figure 2 describes reverse engineered apple samples as agricultural products used in product deformation analysis [3, 10].

(Figure 2. Reverse engineering application samples in deformation analysis of apple(s))

Reverse engineering is rapidly evolving discipline, which covers a multitude of activities [11]. The term ‘reverse engineering’ encompasses a variety of approaches to reproduce a physical object with the aid of drawings, documentation, or computer model data. In the broadest sense, to reproduce anything anyway could be described as reverse engineering [12]. An important area of reverse engineering is the ability to produce digital models of mechanical parts/solid objects from measured data points [13]. More and more models are being built from data generated using reverse engineering 3D imaging equipment and software. In having computer model data, two fundamental steps are highlighted as 3D digitisation (data capture) and surface reconstruction as described in Figure 3 [11, 14-16]. In the application procedure, engineered objects would normally be scanned using laser-scanning or touch-probe technology [17]. In fact, 3D digitisation (data acquisition) technology can be classified as contact (tactile) and non-contact techniques based on the method of 3D data acquisition as shown in Figure 4 [11].

Most especially, non-contact methods such as laser scanning are one of the most suitable applications to obtain digital model data of agricultural products. This method allows for the generation of 3D CAD models of the products with very complex surfaces. In this context, it can be significantly beneficial to use this reverse engineering technology for specific products that have very complex and irregular surfaces such as agricultural materials, not only for virtual and size evaluation of their physical attributes but also to obtain their realistic CAD data which might be used in computer aided rheological investigations.

(Figure 3. Phases in creating CAD models in reverse engineering approach)

(Figure 4. Classification of the 3D digitisation (data acquisition) technology)

In this paper, the focus is on reverse engineering application procedures for the precise description of geometric features of a sample agricultural product: Pecan fruit, which might be used in computer aided rheological analysis. In the following sections of the paper, shelled skin and kernel of the Pecan product have been scanned using 3D laser-scanner and 3D solid models have been produced. After 3D solid models created, geometric measurements have been conducted on the solid models. Subsequently, sample finite element method based deformation analyses were set up for original scanned model and simplified model of the Pecan shell and then visual outputs were compared.

2. MATERIAL AND METHOD

2.1 Application Algorithm

An application algorithm is described in this paper which methodises the application procedures of the reverse engineering approach used in the precise description of the geometric features for various applicable agricultural products. This procedure aims to provide necessary information for the physical and rheological analysis which might be used in the design of related agricultural/food machine systems. The algorithm is shown in Figure 5.

Figure 5. Application algorithm which methodises the application procedures of the reverse engineering approach

2.2 Agricultural Product: Pecan Fruit

Nowadays, consumers are paying more and more attention to the peeled Pecan fruit kernel (without chemical or thermal processes) for their numerous health benefits. This may lead higher increased attention for industrial production and processing of Pecan fruit. Fast harvesting and high quality non-damaged kernel extraction with mechanical shelling (shell cracking) operations of the Pecan fruit are the main demands in industrial fruit processing areas. Therefore, efficient mechanised shelling units/systems needs to be developed. Here, mechanisation design of this shelling operation will be based on the physical deformation characteristics of the Pecan fruit. Since the shell cracking process is the most critical and delicate step for achieving high-quality kernels, knowledge of the mechanical properties of Pecan cultivars is a prerequisite for the design and development of any kind of shelling machine [18]. This issue led the researchers to focus on rheological investigations of the Pecan fruit product. On the other hand, in this study, Pecan fruit *(carya illinoensis)* has been selected as a sample agricultural product because of the highly irregular geometric features of its shell and kernel. The Pecan used in the study has been produced in the Mediterranean region: Antalya at Batı Akdeniz Agricultural Research Institute in Turkey. Some introductory visuals are given in Figure 6.

(Figure 6. Pecan fruit (*carya illinoensis*))

2.3 3D Scanning and Solid Model Creation Processes

In creating 3D CAD data of the Pecan product, a NEXTENGINE 3D Desktop scanner was utilised. The scanning procedure carried out six scanning steps for the whole product surface in both vertical and horizontal positions. HD resolution at macro range options was set up for the scanning process and total scanning time was 20 [min] approximately. Scanned surfaces were aligned and re-meshed into the ScanStudioHD (v.2.02) software and SolidWorks (v. 2015) 3D parametric design software features were used for ordering surface mesh structure and final surface refining of the solid model (Figure 7). As a computer platform, Dell Precision M4800 Workstation was utilised for digitalisation and simulation works in the study.

(Figure 7. Reverse engineering procedures of the Pecan shell and kernel in creating 3D CAD models)

2.4 Measurement of the Geometric Features

Size is an important physical attribute of agricultural products used in screening solids to separate foreign materials, grading of fruits and vegetables, and evaluating the quality of agricultural/food materials. In structural deformation, fluid flow, and heat and mass transfer calculations, it is necessary to know the size of the sample too. It is easy to specify size for regular objects, but for irregular objects the term size must be arbitrarily specified. Shape is also important in these engineering calculations. The shape of an organic material is usually expressed in terms of its sphericity and aspect ratio. Sphericity is an important parameter used in fluid flow and heat and mass transfer calculations and it is an effective feature in structural deformation cases. Surface area is also a significant attribute in rheological analysis. Volume is defined as the amount of three-dimensional space occupied by an object, which affects consumer acceptance and can be calculated from the measured dimensions or by using various methods such as liquid, gas, or solid displacement methods and image processing [2]. The easiest and most accurate way of calculating the volume is to use CAD data [19]. Considering all of this information, related measurements of the geometric features of the Pecan fruit product have been conducted through CAD data and some of virtual outputs are shown in Figure 8.

(Figure 8. Measurement planes of geometric features of the Pecan product through CAD data)

2.5 Comparative Simulation of the Deformations

In this section of the paper, the focus is on the deformation behaviour of the Pecan fruit shell which aims to demonstrate the differences of the deformation behaviour between two different solid models of the Pecan fruit: scanned original geometry and simplified solid geometry. Finite element method (FEM) based deformation simulations have been set up for both of the CAD models. SolidWorks Simulation FEM code (v.2015) has been utilised for these simulation studies. The studies were set up with identical boundary condition definitions. Only the shell structure of the product has been considered and the shell models were compressed between two metal plates (constant moisture content). Compression displacement was set up as 1.8 [mm] which was obtained from previous experimental compression tests of the product during cracking. This value was set up as the average compression displacement to simulate critical condition at the initial crack point. Geometric and contact non-linearities and isotropic linear material model assumptions have been considered under static loading condition in the simulation. The mesh structure has been created through meshing functions of the FEM code considering the geometries (standard mesh size: 4 [mm]) [20]. Some details about the simulation set up are shown in Figure 9.

(Figure 9. Deformation simulation set up)

3. RESULTS AND DISCUSSION

The precise values on the geometric attributes of the Pecan fruit were measured through original geometry CAD data generated from the reverse engineering operation. The CAD software (SolidWorks) evaluation tool extracted the dimensional values (in each of the desired directions), total surface area, geometric volume, shell section areas in desired sections, centre of mass and inertia properties. The density could be also calculated automatically by using a pre-defined real product weight. Some of the numerical values from measured data and measurement visuals are given in Figure 10.

Simulation plots demonstrate that there were different deformation distributions between the models (Figure 11). Although there were identical boundary condition definitions in the simulation set up, deformation behaviour of the models were different from each other because of the different geometric features of each. The simplified geometry has a fully smooth surface and is fully symmetric geometrically in comparison to the original. Therefore, the simplified geometry showed more symmetric and smooth deformation behaviour than the original scanned geometry. In real life conditions, it is very difficult to estimate the material's deformation behaviour under varying loading cases. This case leads the researchers to make some assumptions in the engineering analysis and these estimations may push the results further from reality, relatively. Here, computer aided design (CAD) and engineering (CAE) tools may help in these types of case for more precise measurement and more realistic calculation estimations. More precise data would lead to the creation of designs for more precise machine systems.

(Figure 10. Measurement results of the Pecan fruit product)

(Figure 11. Simulation plots for deformation behaviour/distribution)

4. SUMMARY & CONCLUSION

In this paper, an application algorithm, which methodises the application procedures of the reverse engineering approach used in accurately depicting the geometric features for various agricultural products, is described. The aim of the approach described has been practised in a case study of an agricultural product (the Pecan fruit) successfully. The original geometry of the product was transferred to the digital environment and precise geometric measurement data were gathered. Additionally, the CAD data was used for comparative rheological investigation by means of FEM based deformation simulation. In this way, it provided the necessary information relating to the deformation behaviour of the product which might be used in the subsequent design of related agricultural/food machine systems. Applying reverse engineering applications are an innovative trend among researchers and designers of industrial technologies. Employing such an approach is assisting researchers to obtain geometric data and calculate characteristics of agricultural materials under various loading conditions which is often very difficult to calculate with experimental tests. Design and manufacturing procedures of agricultural/food machinery systems, which are used in harvest and post-harvest operations, are quite complicated with traditional methods because of the small geometries and complex irregular structure of the agricultural products to be processed. The use of reverse engineering and CAE technologies therefore may provide very important advantages. This study contributes to further research into the development of agricultural machinery and equipment through the utilisation of reverse engineering and CAD tools.

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Figure Captions*

Figure 1. Geometry simplification examples in engineering analysis of agricultural products

Figure 2. Reverse engineering application samples in deformation analysis of apple(s)

Figure 3. Phases in creating CAD models in reverse engineering approach

Figure 4. Classification of the 3D digitisation (data acquisition) technology

Figure 5. Application algorithm which methodises the application procedures of the reverse engineering approach

Figure 6. Pecan fruit (*carya illinoinensis*)

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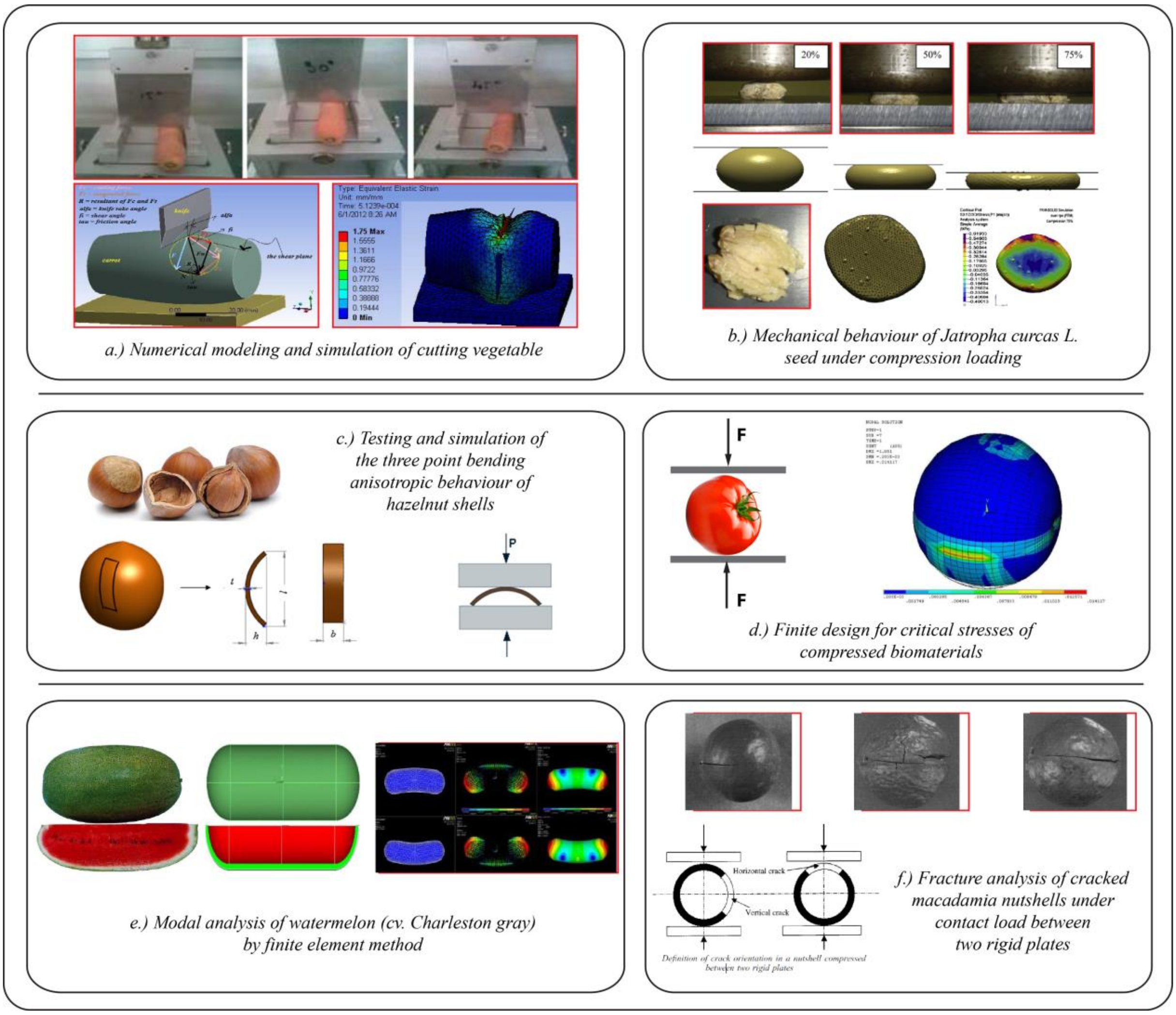
Figure 8. Measurement planes of geometric features of the Pecan product through CAD data

Figure 9. Deformation simulation set up

Figure 10. Measurement results of the Pecan product

Figure 11. Simulation plots for deformation behaviour/distribution



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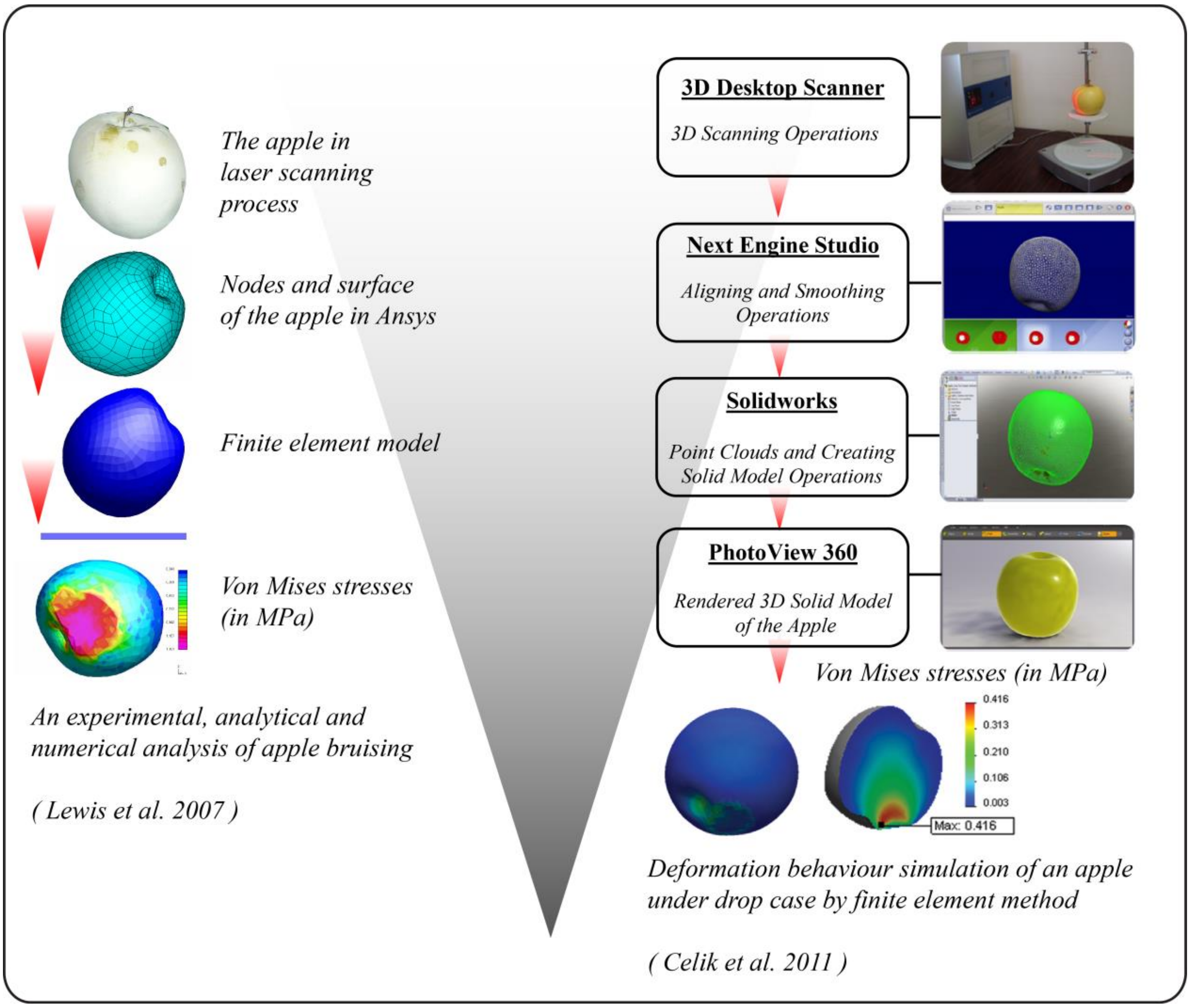

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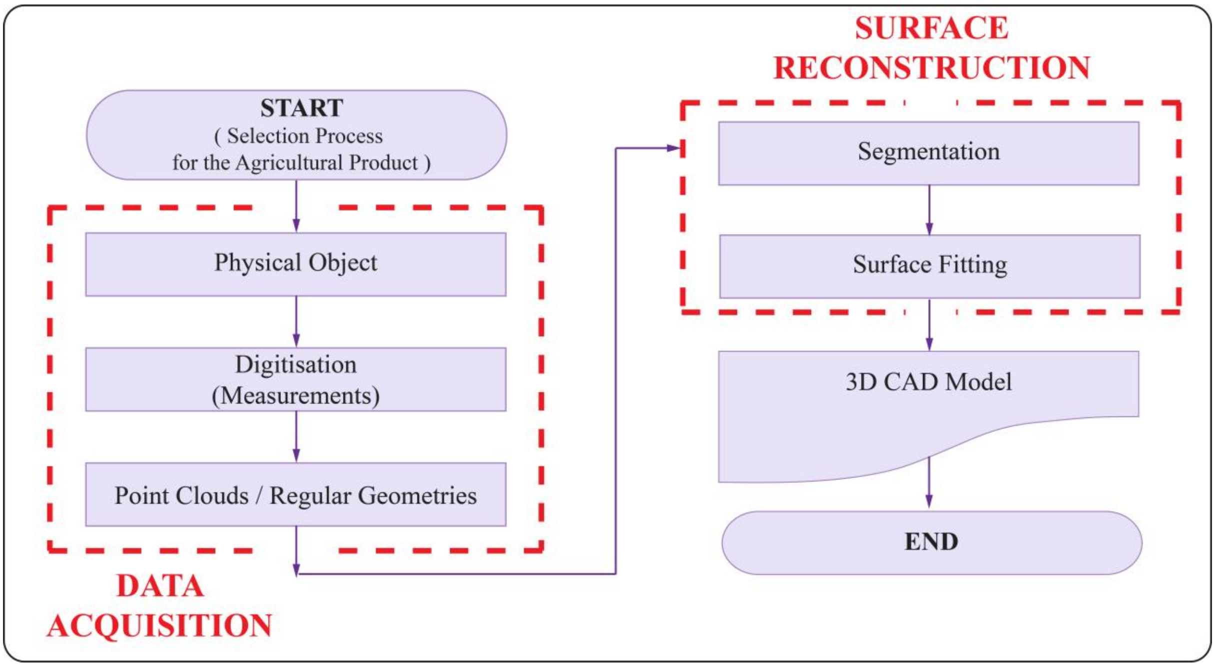

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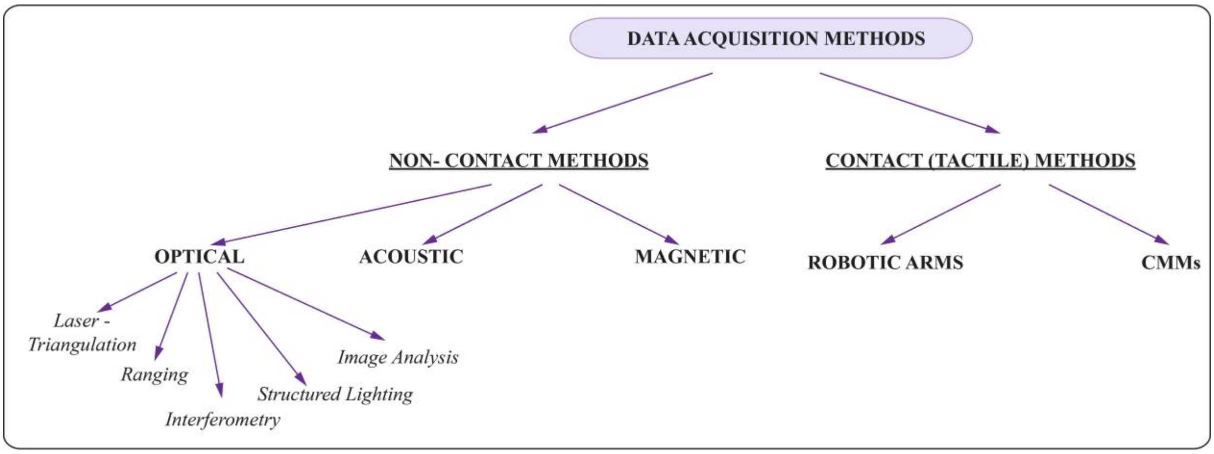

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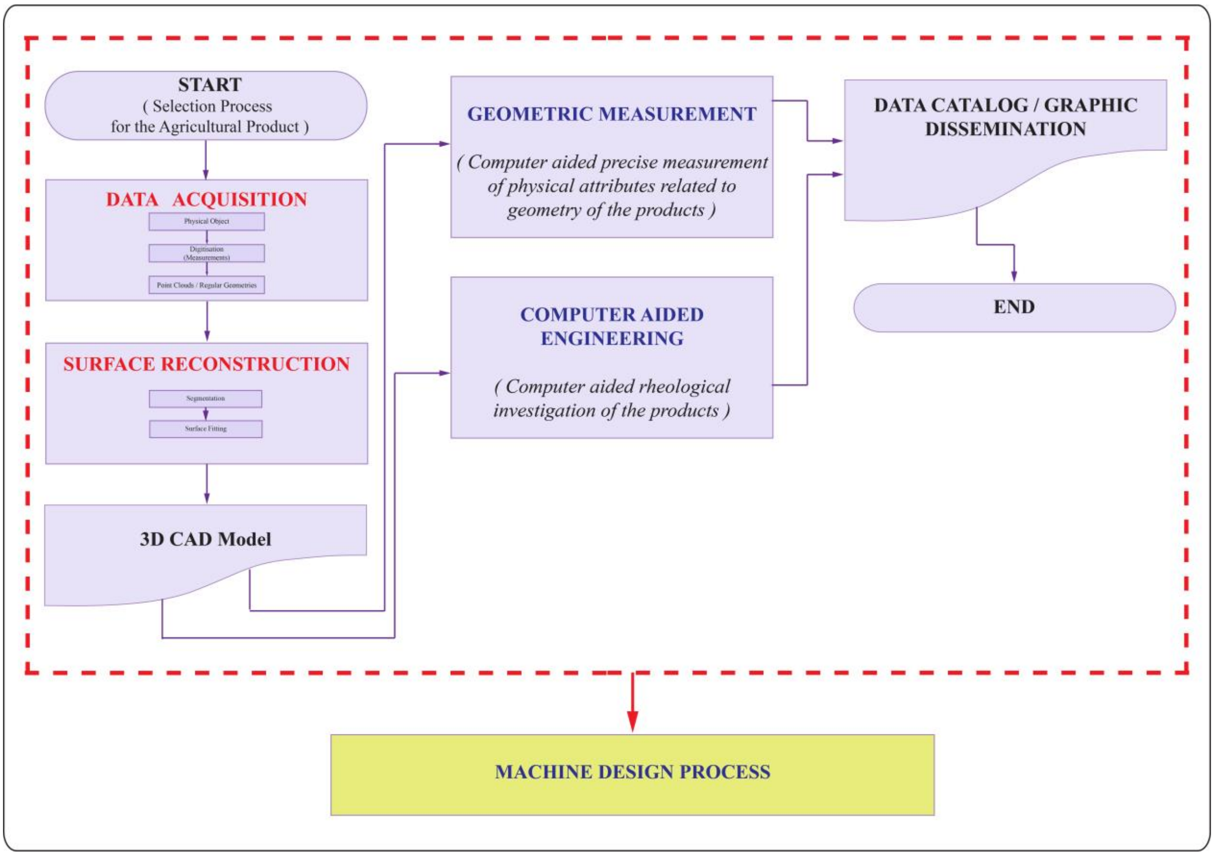

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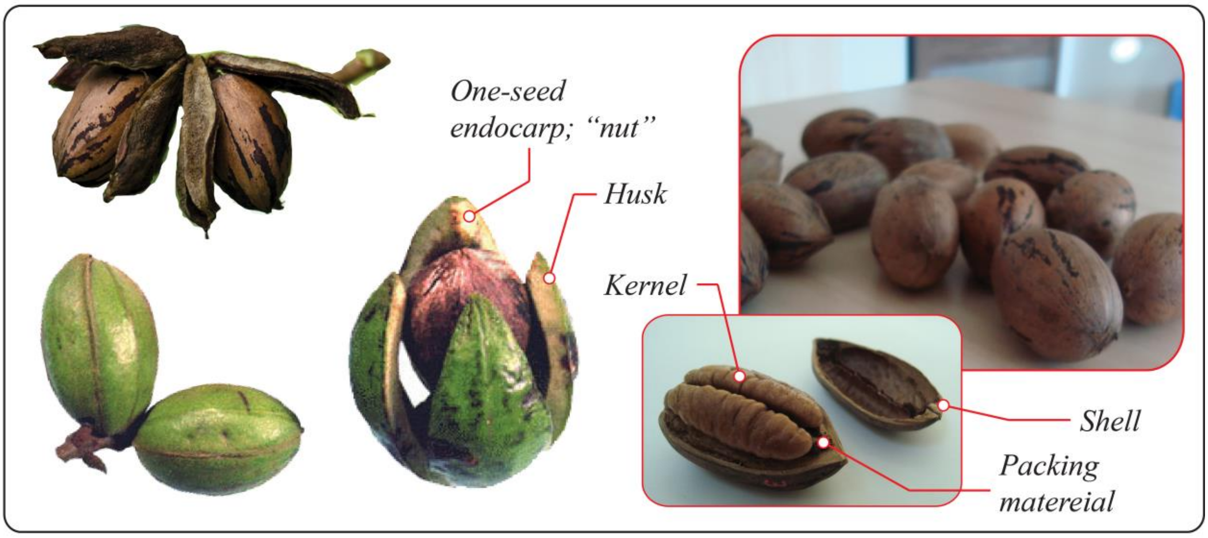
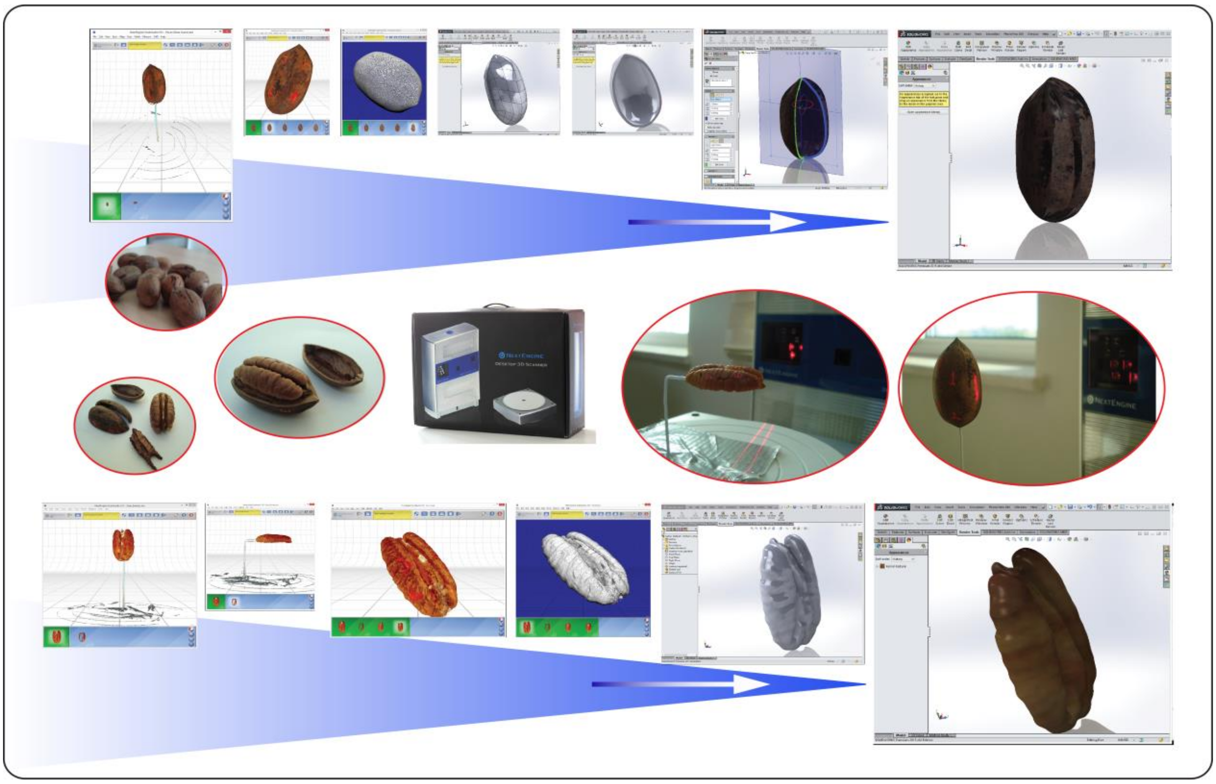


Figure 6. Pecan fruit (*carya illinoensis)*



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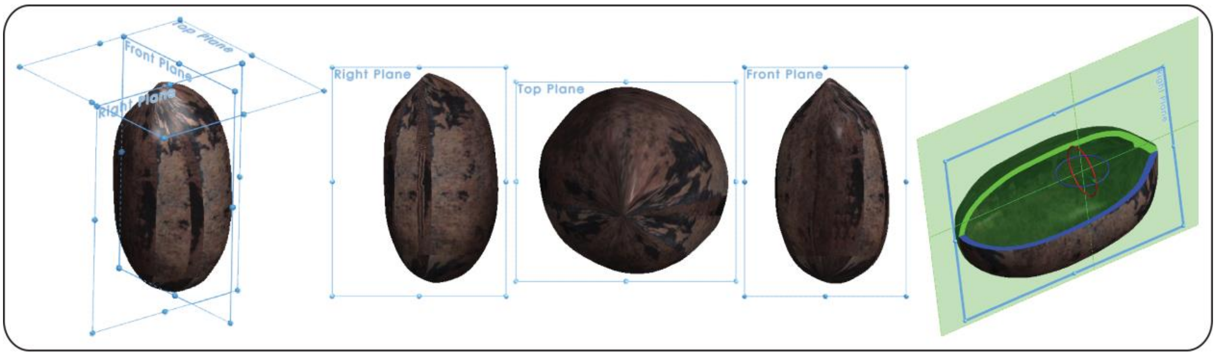
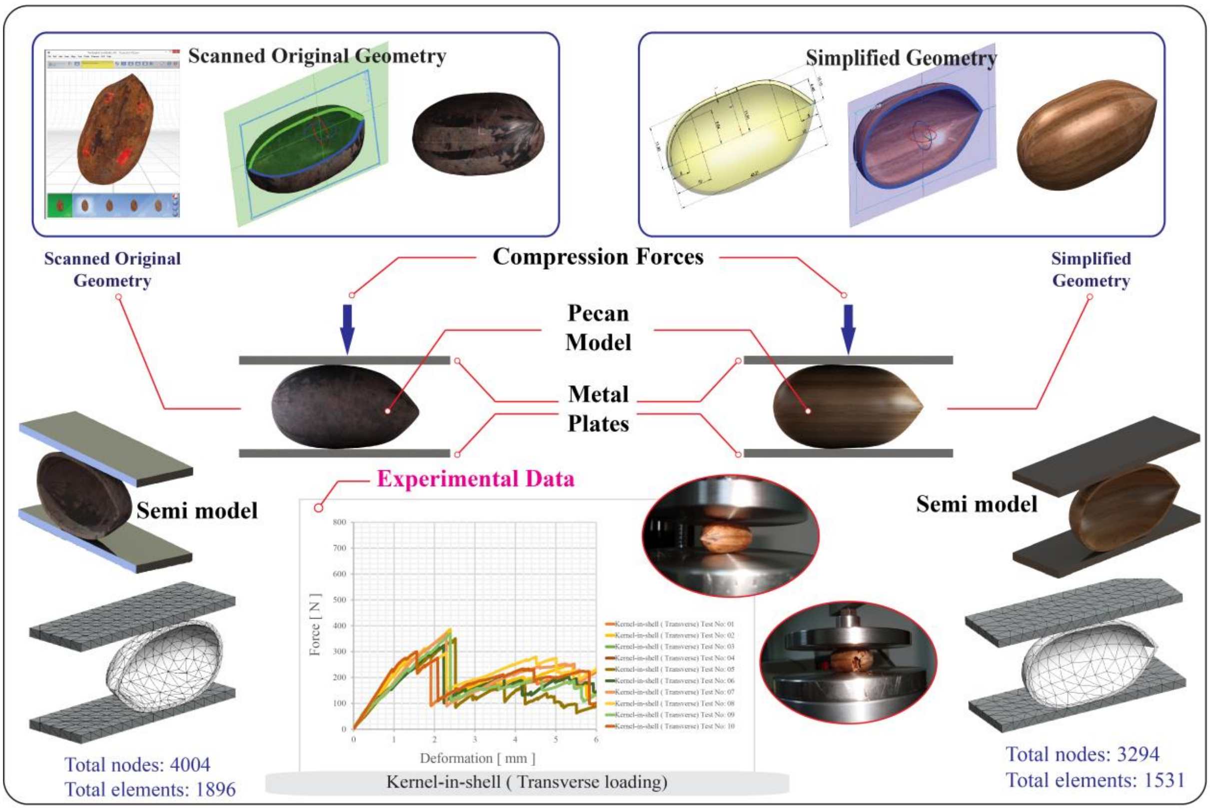


Figure 8. Measurement planes of geometric features of the Pecan product through CAD data



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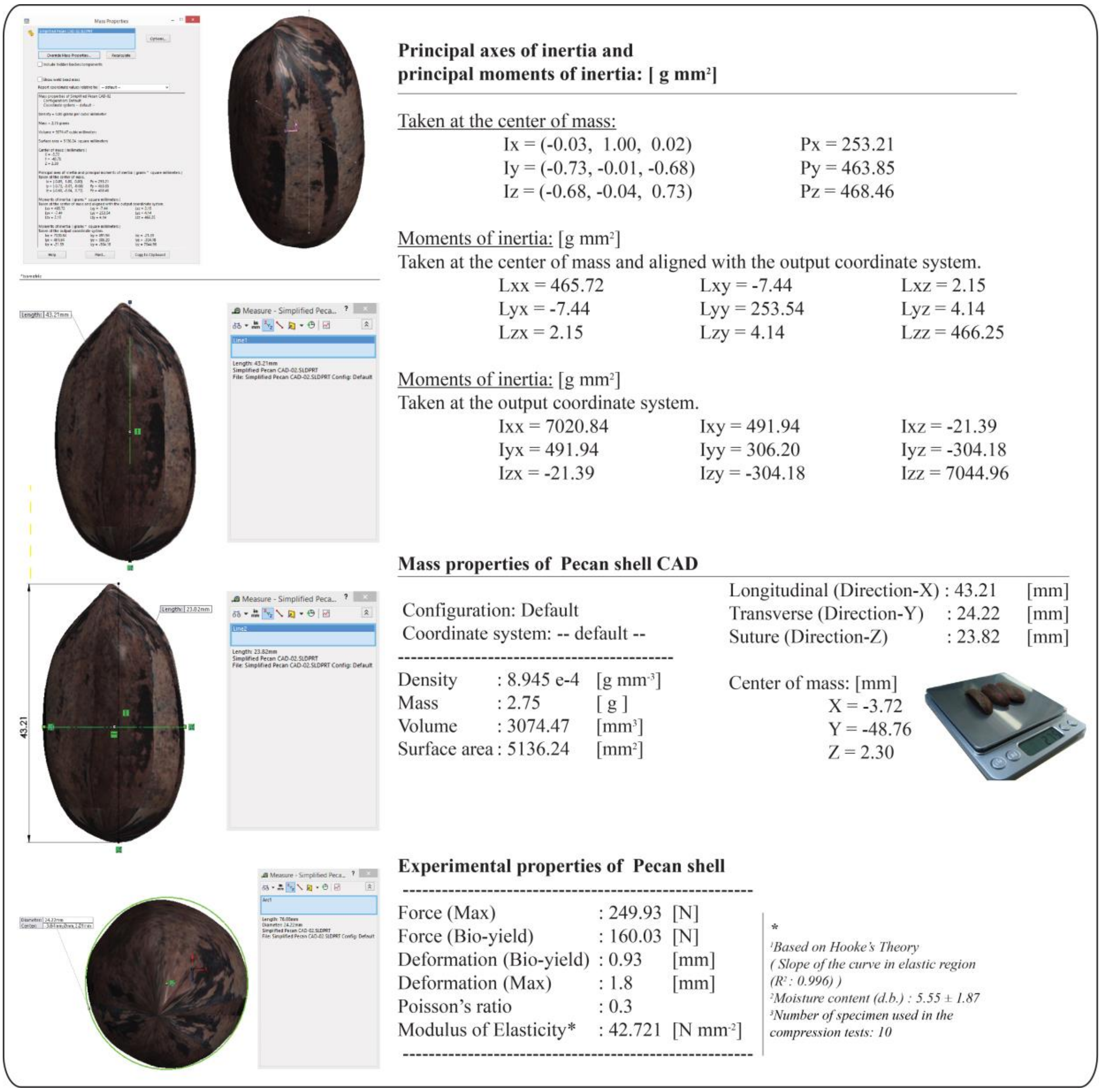

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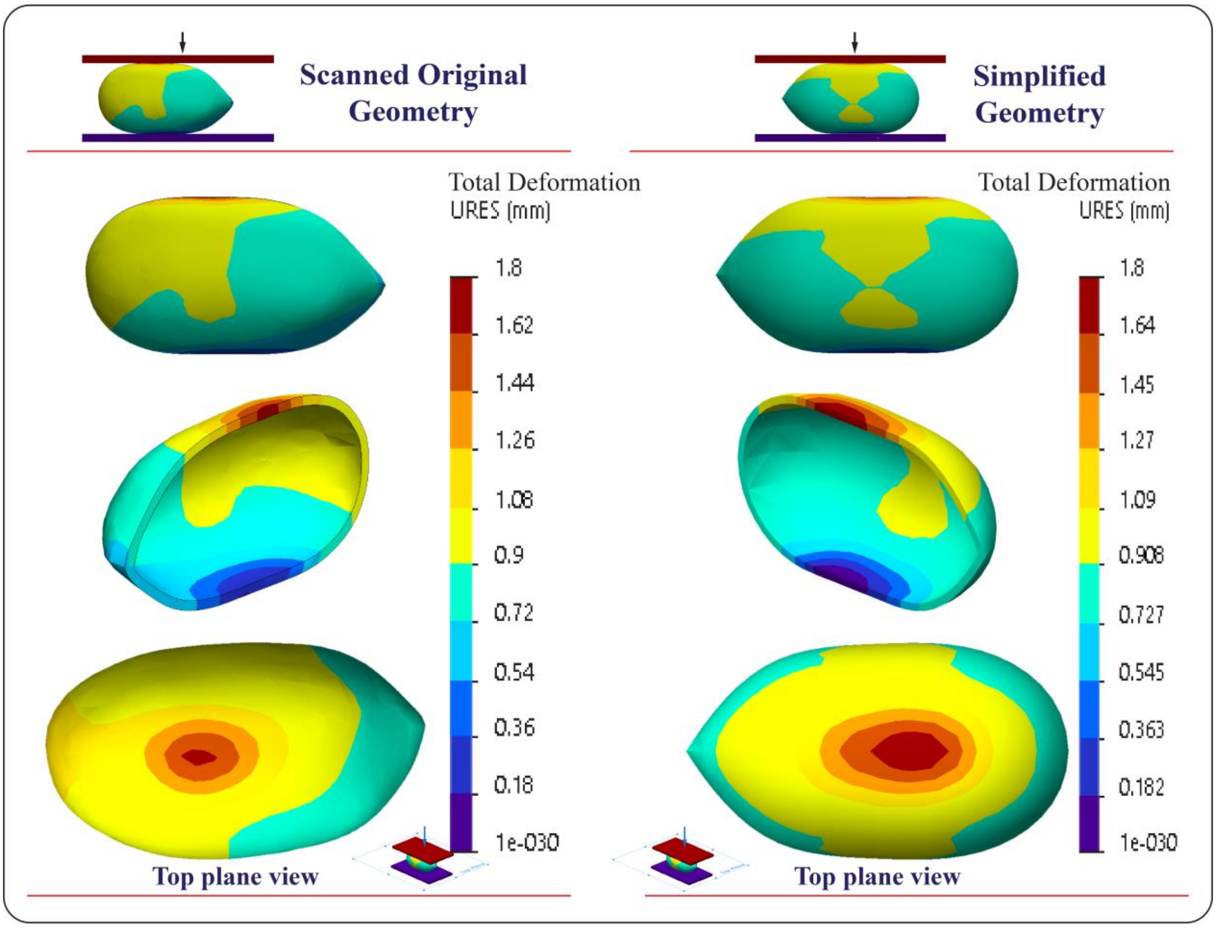

Figure 11. Simulation plots for deformation behaviour/distribution