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Methodology for Generating Solid Three-Dimensional Models from Computed Tomography Using Academic and Open-Source Software

Metodología para la generación de modelos sólidos tridimensionales a partir de tomografías computarizada mediante software académico y de código abierto

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Abstract

The integration of image processing techniques for the generation of three-dimensional biomodels has driven significant advancements in biomedical engineering. These models have key applications in numerical simulations, such as those based on the finite element method allowing detailed evaluation of mechanical and biological environments, as well as the prediction of tissue structural behavior. This article presents a methodological approach to transform medical images into three-dimensional solid models using open-access or academic software, enhancing their applicability in educational and research contexts. The procedure is structured into three main stages: volumetric model generation from DICOM files, model editing and conversion into a solid and basic numerical analysis. Five different approaches were evaluated based on criteria such as number of required steps, process complexity, processing time, computational resource demands, reliance on additional tools, program limitations, and ease of preprocessing for subsequent simulations. From the comparison, it was identified that the combination of 3D Slicer for biomodel generation and Fusion 360 for editing, solid conversion, and numerical preprocessing is the most efficient and accessible alternative. The relevance of this methodology lies in its ability to serve as an essential preliminary step for computational numerical studies focused on areas such as tissue mechanics, biomechanics, and orthopedics. By enabling the generation of precise and adaptable models, this tool facilitates the evaluation of the structural and mechanical behavior of tissues based on the FEM. Consequently, the proposed enhances research and the development of personalized solutions in clinical and academic applications. This approach minimizes reliance on complementary tools.

Keywords: Computed tomography; Three-dimensional imaging; 3D modeling; Numerical analysis; DICOM files.

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Resumen

La integración de técnicas de procesamiento de imágenes para la generación de biomodelos tridimensionales ha impulsado avances significativos en la ingeniería biomédica. Estos modelos tienen aplicaciones clave en simulaciones numéricas, como las basadas en el método de elementos finitos que permiten la evaluación detallada de entornos mecánicos y biológicos, así como la predicción del comportamiento estructural de los tejidos. En este artículo se presenta un enfoque metodológico para transformar imágenes médicas en modelos sólidos tridimensionales utilizando software de acceso abierto o académico, mejorando su aplicabilidad en contextos educativos y de investigación. El procedimiento se estructura en tres etapas principales: generación del modelo volumétrico a partir de archivos DICOM, edición del modelo y conversión en un sólido, y análisis numérico básico. Se evaluaron cinco enfoques diferentes con base en criterios como número de pasos requeridos, complejidad del proceso, tiempo de procesamiento, demanda de recursos computacionales, dependencia de herramientas adicionales, limitaciones del programa y facilidad de preprocesamiento para simulaciones posteriores. A partir de la comparación, se identificó que la combinación de 3D Slicer para la generación de biomodelos y Fusion 360 para edición, conversión de sólidos y preprocesamiento numérico es la alternativa más eficiente y accesible. La relevancia de esta metodología radica en su capacidad de servir como paso previo esencial para estudios numéricos computacionales enfocados en áreas como la mecánica de tejidos, la biomecánica y la ortopedia. Al permitir la generación de modelos precisos y adaptables, esta herramienta facilita la evaluación del comportamiento estructural y mecánico de los tejidos con base en el FEM. En consecuencia, la propuesta potencia la investigación y el desarrollo de soluciones personalizadas en aplicaciones clínicas y académicas. Este enfoque minimiza la dependencia de herramientas complementarias.

Palabras clave: tomografía computarizada; imágenes tridimensionales; modelado 3D; análisis numérico; archivos DICOM.

1. Introduction

Several imaging techniques are available to generate 3D representations of affected areas, providing detailed information about the material's characteristics. This information is stored in different formats depending on user requirements [1], [2]. One of the most widely used techniques is computed tomography (CT), which has become a fundamental radiographic tool in medical diagnostics, enabling detailed images of different sections or planes of the human body [3].

CT uses X-rays projected around the patient as the device rotates, capturing high-resolution cross-sectional images or "slices." These slices are then integrated to create three-dimensional representations, thereby facilitating the diagnosis of complex anomalies, such as tumors, which are challenging to detect using conventional X-rays [4]. Tomographic images are interpreted using Hounsfield Units (HU), a quantitative scale employed in certain imaging studies to describe the varying radiodensity levels of human tissues [5], [6]. HU values range from -1000 for air (black) to 1000 for dense tissues (white) [7], as illustrated in Figure 1. Modern CT equipment can detect up to 4096 shades of gray; however, monitors display only 256 shades, and the human eye perceives approximately 20 shades. This capacity to quantitatively differentiate tissue densities is critical for the precise analysis of specific tissues in the body [8].

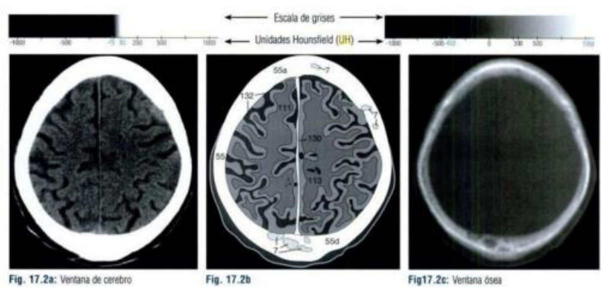


Figure 1. Example of the HU grayscale scale [7].

Due to its detailed visualization capabilities, CT has become increasingly interesting for engineering applications in the biomedical field. Significant opportunities are emerging, particularly in the creation of personalized 3D *biomodels* tailored to each patient, such as prostheses customized to the specific anatomical characteristics of individuals. Furthermore, these 3D representations enable the simulation of physical prototypes through techniques such as 3D printing, offering cost-effective and high-precision solutions for the design of prostheses and other medical devices [9].

This study aims to develop a comprehensive procedure for the creation of solid 3D images from CT scans. The proposed procedure is structured into three sequential stages: first, the generation of a 3D *biomodel* from DICOM (Digital Imaging and Communications in Medicine) files; second, the editing of the generated model, with emphasis placed on surface smoothing and its conversion into a solid model; and finally, the implementation of preprocessing steps required for numerical analysis to assess the mechanical response of the model under simulated conditions. Throughout each stage, various software programs are investigated and evaluated to asses those that yield the best results based on predefined requirements.

In the initial stage of *biomodel* generation, several programs capable of reading DICOM files are explored, including RadiAnt [10], InVesalius [11], 3D Slicer [12], ITK-SNAP [13], and Mimics Medical [14]. Subsequently, software tools for editing and converting models into solids are evaluated, such as Meshmixer [15], MeshLab [16], Fusion 360 [17], SpaceClaim [18], and Blender [19], enabling optimization of the model generated in the previous phase

Finally, various software options are considered for numerical analysis, including Ansys [20], Fusion 360 [17], Solidworks [21], Abaqus [22], Inventor Professional [23], and PTC Creo [24], aiming to identify the tool that provides the most effective interpretation of the solid model's results.

The aim of the present work is to establish an accessible methodology to be used and adapted for various applications in biomedical engineering and biomechanics. The versatility of the procedure, focused on the use of open-access software or Software that are available with academic/student licensing version, ensures that the results can be replicated in academic and research settings, thereby promoting the development of innovative solutions in the field of medical technology.

2. Metodology

This section describes the data, tools, and procedures used to generate solid 3D images from CT scans for numerical analysis of biomodels. The procedure is structured into three stages: the generation of the 3D biomodel, the editing and conversion of the model into a solid representation, and numerical analysis. In each stage, various open-access software programs or academic versions were employed and selected based on the specific characteristics and requirements of each phase.

2.1. Data and Tools

For the development of the 3D model, medical images in DICOM format were used. This format is an international standard for the storage and exchange of biomedical images, ensuring compatibility across equipment and applications from various providers [25]. These images were processed and manipulated using various software tools, which are detailed in the subsequent stages of the procedure.

2.2. Procedure Stages

2.2.1. Generation of the 3D Biomodel

In the first stage, software capable of reading DICOM files and generating 3D images from the provided data was selected. Initially, a list of five applications capable of processing such files and reconstructing 3D images was reviewed (see Table 1).

Specific tools for the visualization and manipulation of medical images, as well as segmentation and export options in various compatible formats, were included in each program. These features were deemed essential for subsequent editing and analysis stages. The final evaluation resulted in the selection of InVesalius, RadiAnt, and 3D Slicer. This selection was based on the prioritization of open-access software or free trial versions over commercial options, as well as the availability of libraries or support materials to facilitate their use.

Table 1. Comparison of software features for generating 3D models from DICOM files

Software [10], [11], [12], [13], [14]	**DICOM Import**	**Example Libraries**	**STL Export**	**Access Type**	**License Cost***
InVesalius	Yes	Yes	Yes	Open access	Free
RadiAnt	Yes	No	Yes	Commercial, monthly trial	39 EUR (Annual plan)
3D Slicer	Yes	Yes	Yes	Open access	Free
Mimics Medical	Yes	No	Yes	Commercial	Information not available
ITK-SNAP	Yes	No	Yes	Open access	Free

*Prices may vary depending on the region and current promotions. It is recommended to contact authorized distributors in each country for precise costs.

- InVesalius [11]. It is an open-access software that includes tools for segmentation using thresholding and manual selection. In this study, a knee DICOM file was used to import and segment the bone tissue, resulting in a 3D surface exportable in STL format (Figure 2). The same DICOM file and export format were used across all evaluated software programs. To visualize and manipulate the generated surface, the procedure to follow in InVesalius is summarized in diagram (Figure 3).

- RadiAnt [10]. Requires a DICOM file from an external source, as its free trial version does not include a gallery of freely accessible files. Segmentation is performed using predefined tissue lists based on HU. These categories include bone tissue, segmented with high HU thresholds, soft tissues like muscles and fat with an intermediate HU range, liquids such as blood or water with low HU values, and air, typically in the lungs, with HU close to -1000. While these predefined categories are useful for general segmentations, they may not provide the necessary flexibility for analyzing more specific tissues or performing detailed segmentations without additional adjustments or the use of more specialized software. RadiAnt include a useful tool called “Scalpel” for custom selection. Figure 4 shows the workflow diagram for generating the 3D solid.

- 3D Slicer [12]. 3D Slicer is an open-access program offering a wide range of tools for the visualization and manipulation of medical images. Additionally, it provides an extensive library of example data (Figure 5). The software includes an advanced segmentation tool called “Segment Editor,” which allows the simultaneous creation of multiple segments and the manual, customized selection of value ranges for segmentation. The output can be exported in several formats, including STL. Figure 6 illustrates the workflow diagram.

2.2.2. Editing and Conversion to a Solid Model

After converting the model to STL format, editing software was used to transform it into a solid body for numerical analysis. This phase included the evaluation of software such as Meshmixer [15], Fusion 360 [17], and SpaceClaim [18]. Table 2 highlights specific features of these solid models in terms of editing capabilities, access, and costs.

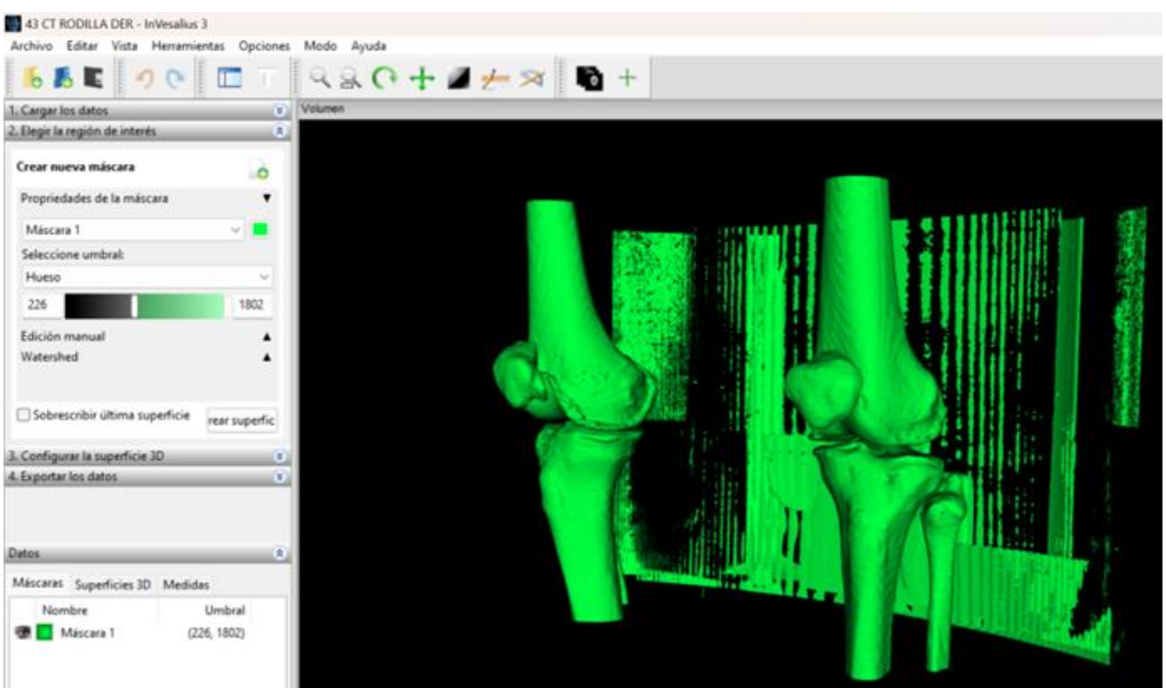


Figure 2. Surface generated using InVesalius software.

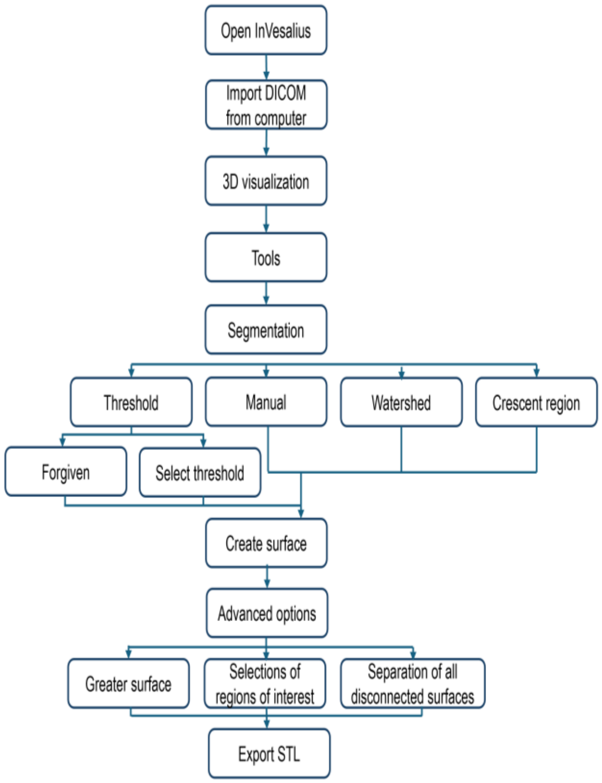


Figure 3. Workflow diagram for InVesalius use.

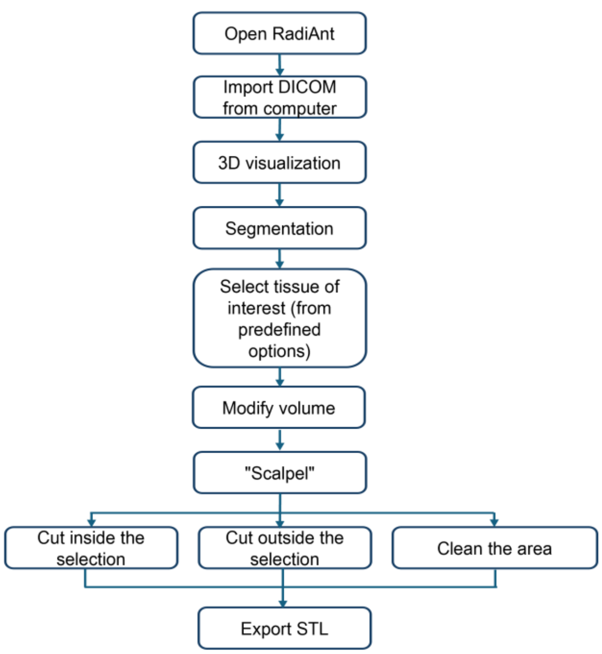


Figure 4. Workflow diagram for the procedure using RadiAnt.

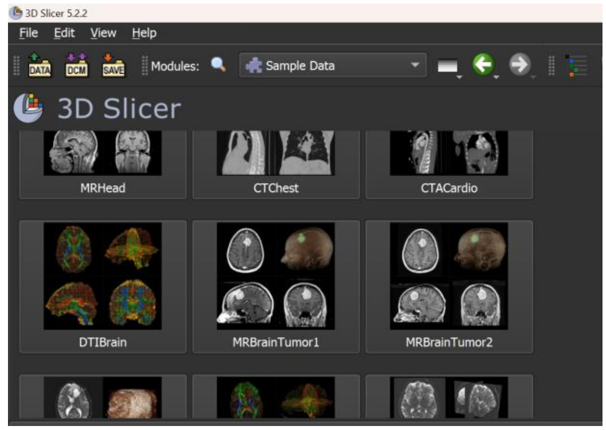


Figure 5. Example data library in 3D Slicer.

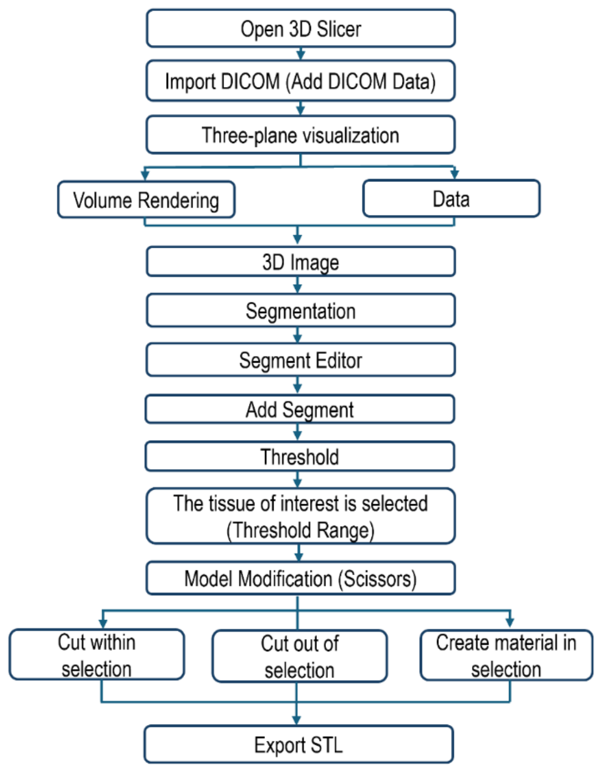


Figure 6. Workflow diagram for using 3D Slicer.

- Meshmixer [15] and SpaceClaim [18]. These programs enable mesh modification through tools such as "Make Solid" and "Reduce," but require additional software for the final solid conversion. Editing within these programs included adjustments to the mesh and surface smoothing to optimize the model prior to solid conversion. Figure 7 and Figure 8 illustrate the respective workflows.

Table 2. Comparison of features in software for model editing and conversion to solids

Software [15], [17], [18]	**STL Import**	**Mesh Modification**	**Solid Conversion**	**Access Type**	**License Cost***
Meshmixer	Yes	Yes	No	Open access	Free
SpaceClaim (Workbench suite)	Yes	Yes	No	Commercial and academic (limited)	$3000 USD/year (approx.)
Fusion 360	Yes	Yes	Yes	Commercial, academic (unlimited)	$680 USD/year; free for academic and personal use

*Prices may vary depending on the region and current promotions. It is recommended to contact authorized distributors in each country for precise costs.

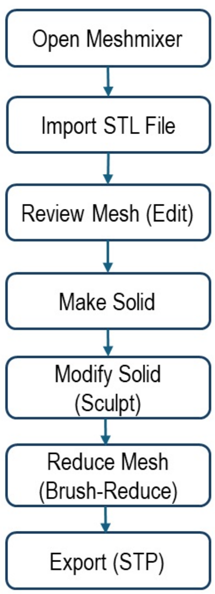


Figure 7. Workflow for using Meshmixer.

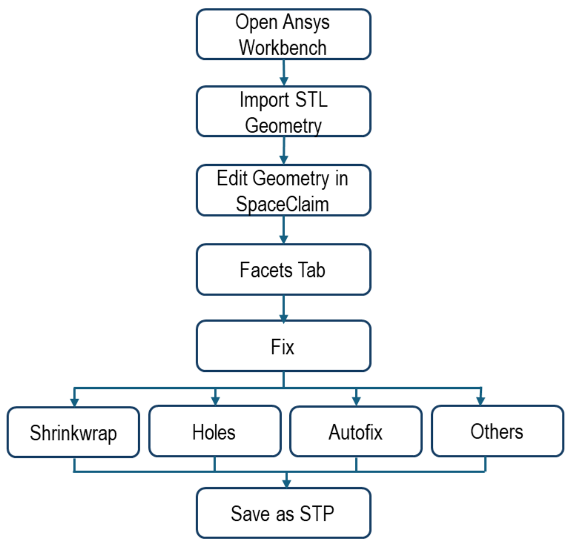


Figure 8. Workflow for using Space Claim.

- Fusion 360 [17]. In this evaluation, the academic version of Fusion 360 was used. The software includes several tools for mesh modification, notably the "Repair-Rebuild" tool, which preserves the shape of the mesh body while generating a new mesh with more regular elements at a customizable density. Another feature highlighted is the "Reduce" tool, which allows the number of elements to be decreased to a desired percentage of the original quantity. Additionally, Fusion 360 enables the conversion of a mesh body into a solid using its "Mesh Conversion" tool, which is highly practical and efficient as it eliminates the need for additional software to complete this second stage. Figure 9 illustrates the workflow.

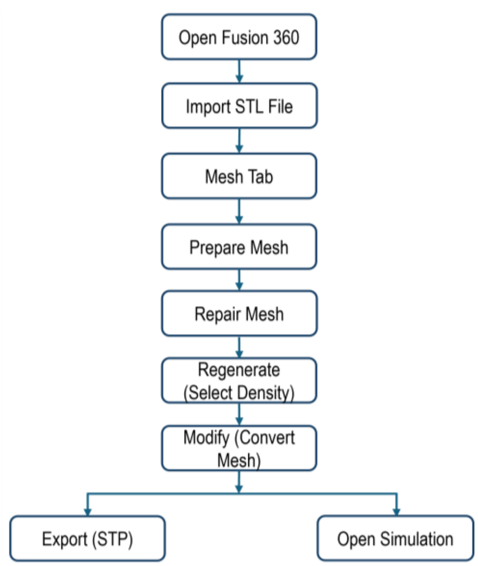


Figure 9. Workflow for using Fusion 360.

2.2.3. Basic Numerical Analysis of the Model

The final stage of the procedure aims to perform numerical preprocessing on the solid 3D model. This step allows for an evaluation of the robustness of the generated geometry and the adequacy of the resulting mesh for further computational manipulation and numerical evaluation. During this stage, mesh generation is assessed, along with the ability to include boundary conditions and conduct a simple numerical evaluation to verify that no errors exist in the generated solid model. Various software tools with structural and mechanical analysis capabilities were investigated such as Ansys, Abaqus, SOLIDWORKS, Fusion 360, PTC Creo, and Inventor. The ability to import and export files, access type, and costs were considered. Table 3 summarizes the results.

Each of these programs provides specific tools for simulating the structural conditions of the model, such as the application of loads and constraints, mesh generation, and the calculation of stress, strain, and safety factors using finite element method. An initial reduction of the software list was performed based on costs, prioritizing compatibility and considering whether some programs had been previously evaluated. As a result, the final evaluation included the Ansys and Fusion 360 software packages.

- Ansys [20]. The *Static Structural* module was used to generate meshes, apply loads, and set boundary conditions for the solid model. A basic numerical analysis was conducted to verify the software's ability to evaluate stresses and deformations under specific loading conditions. Ansys offers the versatility to import geometries in multiple formats, making it reliable and highly regarded within the user community. However, its use as a simple verifier of the solid model's quality can be complex, and the learning curve for mastering basic functions is steep. Figure 10 illustrates the workflow diagram for performing static analysis in Ansys.

- Fusion 360 [17]. Although primarily a design-oriented tool, Fusion 360 includes simulation modules that enable basic structural analysis. For this project, the static stress analysis module was utilized, which is particularly accessible due to its intuitive interface. Compared to Ansys, Fusion 360 provides a simplified user experience for meshing and setting boundary conditions, such as forces and displacements, making the simulation process more straightforward for users seeking a quick approach without advanced configurations.

Fusion 360, the static analysis type was selected to evaluate the quality of the generated solid. Loads and constraints were applied similarly to the configurations in Ansys, and an automatic mesh was generated, adapted to the geometry of the model.

The results in Fusion 360 are presented automatically and are inherently tied to the selected analysis type, eliminating the need to configure each result separately.

Table 3. Comparison of features in numerical analysis software

Software [20], [21], [22], [23], [24]	**Compatible File Formats**	**Types of Analysis**	**Access Type**	**License Cost***
Ansys	.igs, .stp, .x_t, .sat, .catpart	CFD, finite element analysis, deformation	Commercial, Educational (limited)	Approximately $3,000 - $8,000 USD per year
Abaqus	.inp, .x_t, .sat, .stp, .igs, STL	Stress and strain, fracture, fatigue	Commercial, Educational (limited)	$19,000 USD per year
SOLIDWORKS	.sldprt, .igs, .stp, .x_t, .sat	Stress, strain, motion	Commercial, Educational (unlimited)	Annual subscription (Standard): €3,480
Fusion 360	.f3d, .igs, .stp, .x_t, .catpart	Stress, strain, CFD, fatigue	Commercial, Educational (unlimited)	Annual subscription: $680 USD
PTC Creo	.prt, .igs, .stp, .x_t, .sat	Motion, loads, stress, strain	Commercial, Educational (limited)	Design Essentials package starting at $2,780 USD
Inventor	.ipt, .igs, .stp, .x_t	Stress, strain, loads	Commercial, Educational (unlimited)	Annual subscription: $2,385 USD

*Prices may vary depending on the region and current promotions. It is recommended to contact authorized distributors in each country for precise cost information.

This feature allows for a quick assessment of the quality and suitability of the generated solid. Figure 11 illustrates the corresponding workflow.

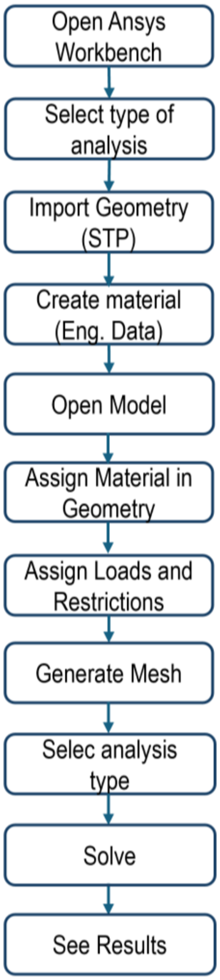


Figure 10. Workflow diagram for using Ansys.

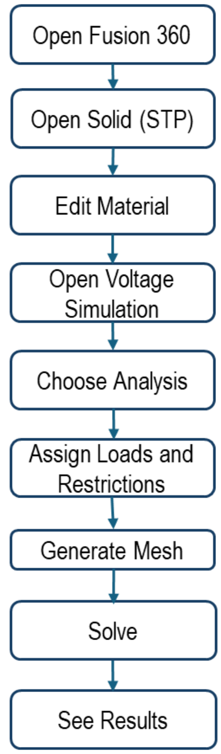


Figure 11. Workflow diagram for numerical analysis in Fusion 360.

3. Results

3.1. Generation and Selection of Concepts

To establish a comprehensive procedure for obtaining solid 3D images from CT scans, the individual evaluation of each software tool is considered insufficient. It is necessary for complete procedural concepts to be developed, integrating the three stages defined in the methodology. Each concept incorporates a different software tool for at least one stage of the process, allowing alternatives to be compared and the most suitable option to be selected. The specific tools for each concept are shown in Table 4.

Table 4. Concepts Developed for the Procedure

Concept	Generation of the 3D Biomodel	Editing and Conversion to Solid Model	Basic Numerical Analysis
Concept 1	RadiAnt	Meshmixer + Fusion	Fusion
Concept 2	3D Slicer	Meshmixer + Fusion	Ansys
Concept 3	InVesalius	SpaceClaim + Fusion	Ansys
Concept 4	3D Slicer	Fusion	Fusion
Concept 5	3D Slicer	Fusion	Ansys

Some of these software tools, particularly those used in the second stage, require additional plugins or complementary programs to achieve the desired outcome for the subsequent phase. For this reason, certain concepts involve the combination of multiple software tools during the editing and solid generation stage. It is important to highlight that all the software tools utilized for the creation of these concepts are either open-access or available in academic versions, ensuring that any student can replicate the procedures without significant difficulty. Each concept was verified by performing the procedure in the most consistent manner possible to facilitate the comparison of results.

For the comparison, identical conditions were applied to all concepts, using the same DICOM file and maintaining a similar selected volume portion across all procedures. The comparison criteria included the number of steps required to complete each stage, the time needed to perform the entire process, the computational resources required, the need for additional software to complete a stage, the limitations of the programs, and the simplicity of numerical analysis preprocessing. As all criteria were considered equally important, the same weight was assigned to each. These details are presented in Table 5.

Table 6, referred to as the Pugh Matrix [26], is presented. This methodological approach was used to identify the most suitable concept to meet the project objectives. The decision matrix results indicate that Concept 4, the Datum, is the optimal choice. This concept uses two software tools: 3D Slicer in the initial stage and Fusion 360 in subsequent stages. The selection is justified by the fact that the other concepts exhibited deficiencies across several criteria compared to the Datum, such as a higher number of steps or the requirement for additional software. Although some concepts show favorable scores in certain aspects, these advantages are insufficient to outweigh the benefits of Concept 4.

Table 7 provides additional information on the evaluation of the concepts.

3.2. Discussion of results

Through the comparative analysis presented in the decision matrix (Table 6), Concept 4 is identified as the preferred option, as it meets the established criteria for comparing the various concepts of the methodology. The outcome of the complete procedure is presented in Figure 12. The final concept manages the generation of the 3D solid from the DICOM image in 25 steps and utilizes two software programs: 3D Slicer in the first stage and Fusion 360 in the subsequent two stages.

Table 5. Comparison Criteria for the Generated Concepts

Criterion	Description	Weight (%)
Number of Steps	Total number of steps in the procedure; fewer steps are preferred.	16.6
Processing Time	Total time required to complete each procedure, under similar conditions.	16.6
Computational Resources	Storage and processing resources required for optimal software performance.	16.6
Additional Software or Plugins	Need for additional software or plugins to complete any stage of the procedure.	16.6
Software Limitations	Limitations in software tools, prioritizing open-access versions.	16.6
Numerical Analysis	Feasibility of performing adequate preprocessing and verifying solid quality.	16.6

3.2.1. Stage 1: 3D Biomodel

In the first stage, which involves the conversion of DICOM files into a volumetric model, significant differences were observed among the evaluated software tools RadiAnt is an accessible option, as it offers a free trial; however, it has limitations, such as restricted usage time, the appearance of pop-up windows, and minimum requirements for memory, processor speed, and storage.

Table 6. Pugh Matrix

Criterion	Weight	Datum (Concept 4)	Concept 1	Concept 2	Concept 3	Concept 5
Number of steps	16.6		-1	-1	-1	-1
Processing time	16.6		1	-1	-1	-1
Resource quantity	16.6		0	-1	-1	0
Additional software	16.6		-1	-1	-1	0
Software limitations	16.6		-1	0	0	0
Numerical analysis	16.6		0	-1	1	1
Total			**-33.2**	**-83**	**-49.8**	**-16.6**

Table7. Details of the evaluated concepts

Concept	Number of Steps	Processing Time	Computational Resources	Additional Software or Plugins	Software Limitations	Numerical Analysis
Concept 1	27	15'00"	RadiAnt, Meshmixer, and Fusion 360, moderate resources.	yes	RadiAnt is limited detecting soft tissue. Fusion 360 is not suitable for advanced simulations.	Static tension in Fusion 360, limited for complex analysis.
Concept 2	28	18'00"	3D Slicer, Meshmixer, and Fusion 360, intermediate resources.	yes	Fusion 360 is not suitable for advanced simulations	Static tension in Fusion 360, limited for complex analysis
Concept 3	30	28'00"	InVesalius, Space Claim, and Fusion 360, higher resource usage.	yes	Space Claim and ANSYS may require additional licenses.	Advanced analysis in ANSYS, suitable for detailed simulations.
Concept 4	25	16'00"	3D Slicer and Fusion 360, moderate resources.	no	Fusion 360 is not suitable for advanced simulations.	Static tension in Fusion 360, suitable for basic analysis.
Concept 5	28	19'00"	3D Slicer, Fusion 360, Ansys, moderate.	no	ANSYS may require additional licenses.	Advanced analysis in ANSYS, suitable for detailed simulations.

These factors may impact on the quality and flexibility of the model. For instance, using RadiAnt to segment high-resolution images may result in less precise segmentation if the usage time is limited, which would affect the final quality of the biomodel.

InVesalius, on the other hand, while intuitive and easy to use, has limitations in volume customization. If a more detailed model or more precise segmentation is required, InVesalius does not offer the same flexibility as other tools, which could limit its applicability in more complex projects that require modeling fine details of anatomical structures.

3D Slicer, however, excels in its ability to perform precise segmentation, which is essential for obtaining a high-quality model. The main disadvantage, though, is its higher computational resource requirements. This means that if the system used lacks sufficient processing power, the image processing and model generation time would be significantly extended, which may not be ideal in environments with hardware limitations.

3.2.2. Stage 2: Editing and Conversion to Solid Model

In the second stage, where the 3D model is modified and converted into a solid, Fusion 360 stands out for its versatility. This software not only allows precise modification of 3D models but also converts meshes into solids more efficiently than other programs. The main advantage of Fusion 360 is that it integrates modeling, editing, and conversion tools into a single platform, reducing the need for additional software. For example, when importing a 3D Slicer model into Fusion 360, smoothing and mesh modification tools can be applied quickly without losing precision, which facilitates a continuous workflow.

In comparison, programs such as Meshmixer and SpaceClaim require additional software to complete the mesh-to-solid conversion process.

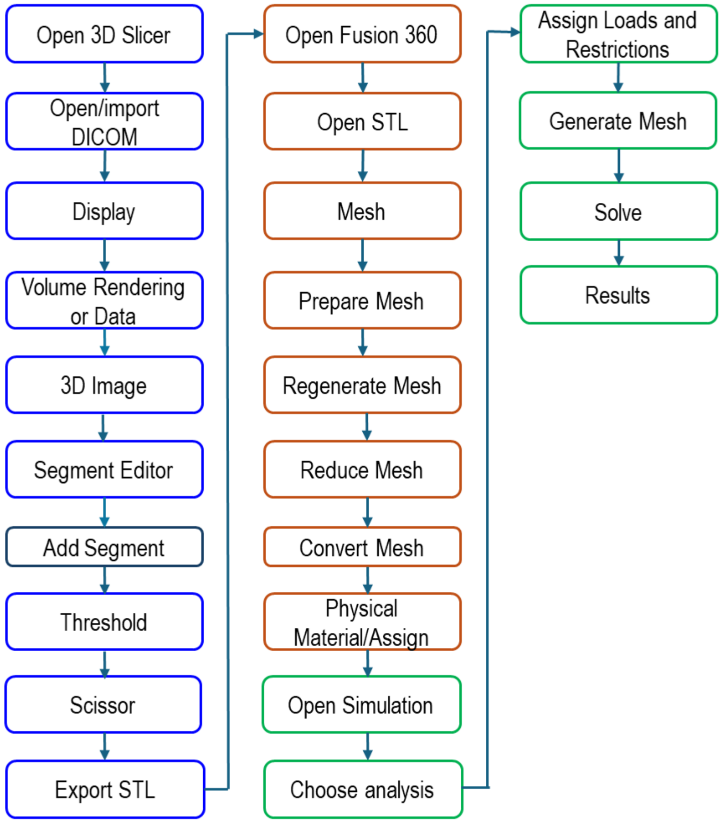


Figure 12. Workflow Diagram of the Final Procedure.

Although Meshmixer is easy to use and quite accessible, it does not allow direct mesh-to-solid conversion without the intervention of other programs, which may slow down the process and cause inconvenience. SpaceClaim, while offering good editing capabilities, lacks direct conversion tools, making integration into a smooth workflow more challenging.

3.2.3. Stage 3: Basic Numerical Analysis

In the third stage, Concept 4 is further justified by its efficiency in preprocessing and performing basic numerical analysis. Although Fusion 360 is not a specialized analysis software, it provides the necessary tools for verifying the quality of the generated solid based on numerical-computational requirements. These capabilities include mesh generation, boundary condition creation, and the ability to conduct basic simulations, ensuring procedural validation.

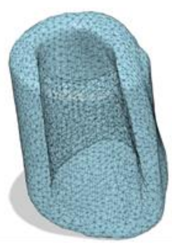
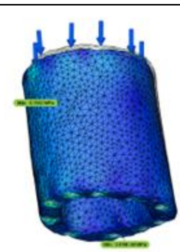
In comparison, Ansys offers a more comprehensive set of features for conducting complex numerical analyses, such as stress and strain simulations in materials. However, its disadvantage lies in its limited educational license and higher computational resource requirements, which could hinder its use in environments with low-performance systems. Additionally, the learning curve of Ansys is considerably steeper than that of Fusion 360, which could pose a challenge for users without prior experience in handling advanced simulation tools.

Through this comparison it can be concluded that Concept 4 (3D Slicer + Fusion 360) is the most balanced, as it optimizes the workflow with the combination of accessible and flexible software. 3D Slicer provides precise segmentation, while Fusion 360 offers a comprehensive approach that enables efficient model modifications and numerical analyses. However, the limitations of each software, such as the higher resource requirements for 3D Slicer and the lack of numerical specialization in Fusion 360, should be considered when applying this methodology in different research or clinical scenarios.

As an example, Table 8 provides an infographic summary consisting of six images of the winning concept. The reconstruction of a proximal tibia segment is illustrated.

The total time required for the process was 16 minutes.

Table 8. Infographic Summary of the Winning Concept Sequences: From Biomodel Generation to Numerical Analysis

Step Description	Image
Resulting volume generated in 3D Slicer from CT scans using the "segment editor" tool, and the biomodel was saved in STL format.	
Volume imported into Fusion 360 from 3D Slicer.	
Resulting volume after applying smoothing tools in Fusion 360.	
Conversion to a solid in Fusion 360.	
Preprocessing for static analysis in Fusion 360: a distributed load was applied to the upper area, and the opposite surface was fixed.	
Results in terms of stress (representative image).	

4. Conclusions

A methodology for generating solid 3D models from CT scans was presented, using open-access software or academic versions. A replicable and accessible method was developed, designed for use in educational and research environments. Five distinct concepts were defined and evaluated, each configured through the combination of specific software tools aligned with the three fundamental stages of the procedure: volume generation, editing and conversion to a solid model, and basic numerical analysis.

Based on the results from the decision matrix (Pugh Matrix), Concept 4 was identified as the optimal choice, integrating the use of 3D Slicer for volume generation and Fusion 360 for model editing, solid conversion, and numerical preprocessing. This concept was selected because it met the defined criteria for selection, including the number of steps required, processing time, computational resource demands, and software limitations. The integration of these tools streamlined the workflow, reducing complexity, minimizing reliance on additional software, and ensuring a high level of precision. Concept 4 stood out in comparison with the other concepts for its ability to optimize each phase of the process efficiently and accessibly. Unlike other concepts, which required the use of multiple tools and additional software, Concept 4 combined 3D Slicer for volume generation and Fusion 360 for editing, solid conversion, and numerical preprocessing, significantly reducing the workflow complexity. This not only resulted in a more streamlined process but also reduced processing time and minimized the need for additional software. Moreover, the use of 3D Slicer and Fusion 360 ensured efficient computational resource usage, compared to heavier alternatives like Ansys, which demand higher processing power and have a steeper learning curve.

The proposed methodology is characterized by its accessibility and versatility, achieved using open-access tools or those available in academic environments. This ensures broad applicability, particularly in resource-constrained contexts. The adaptability of the methodology is also noteworthy. While Concept 4 was identified as the most efficient option, the procedure is sufficiently flexible to integrate alternative software combinations tailored to the specific requirements of each project. This includes, for example, the execution of advanced numerical analyses or compatibility with specialized hardware, significantly broadening its scope of application.

Lastly, the educational impact of the methodology is emphasized, as it fosters practical learning in the fields of medical and biomechanical engineering. The developed procedure provides students and researchers with access to a replicable workflow that not only facilitates the understanding of theoretical concepts but also connects them to practical applications in real-world scenarios. This educational approach strengthens the technical competencies necessary to address contemporary challenges within these disciplines.

It is important to note that this methodology has certain limitations, including its dependence on the quality of DICOM images, as low-resolution images or those with artifacts can compromise the final accuracy of the model. Additionally, the methodology requires a considerable amount of computational resources, especially in the generation of the biomodel, which can pose a challenge in environments with limited hardware. The software selected for numerical simulations, although suitable for basic analysis, is not designed for advanced simulations, which restricts its application in more complex scenarios. Furthermore, the learning curve of the tools used can be an obstacle, especially for students or users with no prior experience. Finally, it would be advisable to conduct clinical validation in real-world settings, as this could improve the applicability of the methodology in medical contexts.

Based on the identified limitations, it is recommended to investigate advanced DICOM image processing techniques, such as artificial intelligence, to improve resolution and reduce artifacts, which would enhance the accuracy of the biomodel. It is also suggested to optimize the use of computational resources through parallelization or cloud platforms, allowing work with larger datasets in environments with limited hardware. To improve the segmentation of complex tissues, it is proposed to explore deep learning algorithms and adaptive segmentation techniques. It is crucial to integrate specialized software, such as Ansys or Abaqus, for advanced simulations that Fusion 360 cannot cover. Additional educational material should be developed, and clinical validations should be carried out to confirm the methodology's effectiveness in real-world environments.

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Autor Contributions

C. Carrasco-Lara: Formal Analysis, Investigation, Methodology, Writing –original draft. B. Amador-Cáceres: Methodology, Writing–review & Editing. G. Serandour-Boniot: Conceptualization, Writing–review. G. Martínez-Bordes: Conceptualization, Investigation, Methodology, Supervision, Writing–original draft, Writing-review, Editing.

Conflicts of Interest

The authors declare that there is no conflict of interests of any kind regarding the publication of the results of our research work.

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