

PREFACE

An outline of this work is presented here—a road map of the journey. The chapters are designed so that they are most comprehensible if followed in the order the material is presented. In addition to dealing with the specifics of how geometry can be created for the purpose of engineering analysis, this work takes a wider outlook on the world of geometry, both of today and yesterday. It shows how the geometry is fundamental to nature and how it is interconnected with the world around us. The historical background provided shows the progression of the geometrical science from the dawn of civilization to the multiple specialized disciplines that the geometry has evolved into today. The world of geometry is a vast ocean and only a few drops of it are presented here. While the work touches upon the complex nature of geometry's axioms and theorems, the presentation aims to be accessible to all technically minded readers.

From the original conception, this publication was intended as a companion for the Author's earlier work—*Heat Transfer Modelling Using COMSOL: Slab to Radial Fin* [1]. Thus, the contents of this publication are complementary to the earlier one, with minimum overlap between the two. This also means that most of the examples used in this work are the same as in the earlier one, providing the reader with opportunity to learn about model creation in this publication and to continue to learn about the analysis step by working with the earlier book.

Chapter 1 is a brief introduction to the world of geometry. The chapter highlights how the geometry surrounds us in all possible forms, in the natural environments and in the artificial ones. It is a science of coordinates, relative locations, and borders that forms part of the worldview that we develop. Some background is provided on the advancements in this field by humans (and other living creatures) from the beginning of creation to the modern time. Our non-human cohabitants of this planet either contributed directly

to this cause (e.g., building honey combs) or indirectly as sources of human inspiration (e.g., dragonfly wings). Honeycomb's hexagon is constructed to the highest level of perfection with no material wasted after the process completion—demonstrating the honeybee's strictest possible adherence to the Lean Six Sigma process. Highly corrugated and stiff dragonfly wings have been mimicked to create flapping micro air vehicles producing thrust and lift by flapping the wings that deform like sails [2,3].

Chapter 2 presents a historical perspective on the progress in geometrical sciences. The developments are organized by time, being grouped into ancient, medieval, and modern periods. Other historical developments covered include information on the subjects of measurement methods and units of measurement. Progression of geometrical concepts from the fundamental to the most complex ones is described along with the interconnections between the geometrical hypotheses.

Chapter 3 talks about connections between creative arts and the science of geometry. Concepts of form, fit, and function, part of the Lean Six Sigma methodology which aims to improve processes, are connected in this work with the geometrical concepts. As part of this concept development, travel dimensions and the archaic Earth's flatness theories are discussed. Interestingly enough, the idea of the Earth's flatness seems to still have its proponents today, demonstrating how even the most obvious realities may still be questioned by some. Examples are provided of geometrical connections to the works of great creators such as Leonardo Da Vinci and to the ones associated with the natural elements of the universe. Design optimization is discussed in this chapter as part of the topology, size, and shape concepts.

Chapter 4 discusses the elements of geometry. These include the definitions such as axioms, topology, and symmetries along with the basic elements used in geometrical constructions such as lines, angles, curves, planes, surfaces, and volumes. Concepts such as topology and symmetry are explained as well.

Chapter 5 discusses the methods to navigate a geometry. Since geometrical coordinates of vertices need to be defined relative to some common frame of reference (point of origin), it is paramount to have such point identified and also define the coordinate system in which their connectivity becomes meaningful. For example, although it may be possible to locate the points on the perimeter of a circle by means of the Cartesian coordinate system using two linear orthogonal coordinates, it is considerably easier to do this using a polar coordinate system by means of the radius and the angle. An overview of the vector algebra is presented at the end of this chapter since knowing its fundamentals is a must to fully understand the examples provided.

Chapter 6 discusses the methods by which geometries are created using commercial software packages. Solid Edge®, PTC Creo®, Autodesk, CATIA™, and SolidWorks® are briefly introduced, highlighting their origins and features. Two main products of MathWorks®, MATLAB® and Simulink, are presented, with the focus on MATLAB and its capabilities to create geometry by not only dragging-and-dropping the pre-designed shapes but also using commands,

formulae, and scripts—with the capability to implement each method of geometry creation as an input file that can be executed like a program. A mapping toolbox, an add-on to MATLAB, is introduced showing how this tool can be used to create custom maps using different projections.

Chapter 7 presents the methodology by which the model geometry can be imported into Finite Element Method (FEM) software, either by using commands or Graphical User Interface (GUI). Challenges which the user may face before, during, and after performing this process (CAD-FEM interaction) are discussed and the recommended methodologies are addressed. One of the commercial FEM tools available is COMSOL Multiphysics®, which is employed in this work for the majority of the geometry creation examples. FEM (and CAD) tools often share common creation, presentation, and organization techniques. Therefore, geometry creation and modeling fundamentals presented in this chapter can be extended to other similar tools. Interfacing tools that are either part of COMSOL Multiphysics core package or add-on modules are presented as well—with the Computer Aided Design (CAD) import module receiving most of the attention.

Chapter 8 focuses on using COMSOL Multiphysics to generate the geometry, and shows how a model in this FEM environment is created. As mentioned earlier, most of the examples used in this work are created using COMSOL Multiphysics add-on CAD module, which requires a dedicated license; however, the core package also provides the basic tools to create geometries, using geometrical elements introduced in Chapter 2 (lines and arcs) and, for example, Boolean operations. Three-dimensional (3D) geometries can be created from the two-dimensional (2D) profiles by extruding these profiles linearly, sweeping them along any curve, or revolving them about an axis. Geometry creation is the first step in any analysis. Next steps are defining physics, materials, analysis types, calculating a solution, and finally post-processing the solution results to extract useful information from them.

Chapter 9 provides case studies with an increasing level of complexity from a slab to radial fin. These shapes, known as *extended surfaces* in the field of heat transfer, have been selected due to their broad range of applications, from bridge construction to furniture, to their use for thermal management—employed in applications from cooking to electronics and aerospace. Variety of shapes are discussed herein so that the reader can review each and decide if they can address some of the design challenges they face. The Webbed radial fin geometry is the most complex one and although it could have been created in a dedicated CAD tool such as Solid Edge, it is created using the FEM CAD module to show what can be done when a dedicated tool is not available and also to highlight the FEM tool geometry creation features. The effort to use this methodology increases the complexity of the task; however, it also facilitates interacting with the FEM tool when setting up the physics and boundary conditions by eliminating any potential misinterpretations that may happen as a result of the geometry import. A *rotini* fin, another structure with complex

geometry, is introduced in this chapter; it is created in a dedicated CAD tool (Solid Edge) and then imported to the FEM tool. A relatively detailed description of the steps taken in order to generate the geometry model, especially the complex ones, where parametric surfaces are extensively used are discussed along with related figures.

Chapter 10 offers an overview of the applications that were created based on the geometry models presented in Chapter 9 (“Extended Surfaces”) and that are included in the companion files to this book. The same files also include COMSOL Multiphysics model files, containing only the geometry models. Applications in this context are a feature provided by COMSOL Multiphysics that allows the analyst to create a user-friendly interface to the problem, providing only a limited number of input controls and output displays. The applications presented here provide the capability to vary some basic geometry and mesh parameters and display the results. A brief overview of the model and application along with the images of the meshed geometry and the application interface are presented for each case study. The purpose of this work is to provide initial guidance for the reader to understand the geometry creation process in a FEM tool, interact with it, review the content on their own, and attempt the examples. Building on these steps, the reader can come up with their own ideas to set up the geometry (or mesh), and identify the steps to be taken to complete the analysis and obtain the solutions.

Chapter 11 talks about *good practices*—the concepts of *recommended* methods versus *preferred* ones are clarified. It is emphasized that there is usually more than one method when creating geometries. The purpose is therefore to choose among the possible methods the one that is both most efficient and most appropriate for the available FEM tool. Several approaches are provided so that the reader can look into the possible solutions when issues occur. There are also examples of how the human mind can be inspired and the nature becomes the source of inspiration when creating geometrical features in the form of ecosystems or places of residence and solace. The steps to be taken before, during, and after geometry import to the FEM model as well as interacting with the imported geometry by specifying tolerances, and under what conditions to relax the tolerance are presented.

Chapter 12 talks about the Lean Six Sigma concepts and how they can apply to this field. The chapter explains how all levels of the product lifecycle, including interactions between the design tool and the designer (e.g., geometry creation) should be considered when process improvement decisions are made. The concept of entitlement is presented as well and what it means to be *entitled* to something but not fully realizing it. It talks about the sources of waste and the approaches to take in order to make more responsible decisions to reduce waste to the extent possible. Furthermore, it is explained what it means to be operating within 99 percent full potential and if this capability is acceptable or considered an excellent or poor performance under the given circumstances. These concepts are expanded upon with regard to geometry creation, importing, defeaturing, and processing within the CAD-FEM environments.

Chapter 13 concludes this work, encouraging application of fair assessment in terms of processing or constructing geometries when initiating the challenge of making geometrical features so that it is effectively employed within a CAD or FEM tool. Much can be learned by studying, but doing must always accompany it.

Appendix A lists COMSOL Multiphysics parameters and geometry sequence steps used to generate a Fibonacci spiral (an approximation of the golden spiral) for the illustration shown in Chapter 4.

Note that there is not a single way to approach geometry creation; neither are there single approaches to create relationships between the components. For example, a part may be rotated to the desired orientation before importing it into an assembly. It is also possible to import the same part into the assembly and then rotate it to the desired orientation. In the latter scenario, mating between certain geometrical features; for example, main coordinates or construction lines may be endeavored to arrive at the same conclusion. Therefore, the Author encourages the reader to attempt the *Examples* and *Case Studies* after completion of the related subject matter more than once, exploring other possibilities to build the same geometry using the knowledge building blocks provided. Moreover, the Author encourages the reader to review the suggested approaches to tackle the geometrical problems both to visualize and understand them, but also to construct them as individual parts first, and then use computer-aided design tools to create the parts as single components or in assemblies only after the conceptualization process has been completed.

