Python for Geometric Modeling: Quick Introduction and Step-by-Step Guide to CAD Applications

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Practical Books

Python for Geometric Modeling: Quick Introduction and Step-by-Step Guide to CAD Applications

by Ronald Martinod, Daniel Correa, and Paola Vallejo
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With heartfelt gratitude to Laura and Angélica, whose unwavering support and patience have been my pillars of strength.
- Ronald Martinod

To my wonderful sister, Juliana.
- Daniel Correa

To my family for their unconditional support.
- Paola Vallejo

Contributors

About the authors

Ronald M. Martinod has been an associate professor at Universidad EAFIT since 2015. He completed his education in mechanical engineering and later obtained a Ph.D. from the University of Lorraine (France) in the School of Computer Science and Mathematics Engineering. He gained experience working on research projects that support organizations in optimizing maintenance policies and the operation of urban transport networks.

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Camilo Herrera is a sound engineer with an MSc in Engineering, whose focus lies in data science and software development. His research is conducted in the field of industrial maintenance, where he dedicates himself to creating robust numerical tools and digital solutions to support decision-making. Currently, he serves as an adjunct professor of Python programming fundamentals.

Table of contents

Preface

What is geometric modeling? It is an area of applied computational geometry that studies methods and algorithms for describing shapes, in which Computer Aided Design (CAD) is the computational representation of an object's geometry. It includes both graphical and non-graphical information. This information is generated and displayed as geometric models, that is, figures; thus, it is possible to edit and analyze the models in different ways.

In this book, we will discover some basic geometric models practically using Python language. It will be a quick introduction and step-by-step guide to CAD applications.

The big difference between this book and other similar ones is that we will adopt a strategy governed by three fundamental elements: (*i*) we will develop concepts with a **theoretical/practical** approach, (*ii*) we will explain each element **step by step**, and (*iii*) we will use many **images** to explain the fundamental elements.

Theoretical/practical: We will explain each concept we develop calmly and briefly, with words that any reader can understand (without going around in circles or using complex expressions). In addition, we will develop multiple pieces of code, examples, and exercises for the reader to practice and understand how to apply each element seen.

Step by step: We will start with short and simple pieces of code. In addition, we will adequately explain each instruction developed. We will not assume that the reader magically understands everything.

Images: We will use supporting images to facilitate understanding multiple concepts and pieces of code (both simple and complex). We will use diagrams and screen outputs for the reader to verify their progress.

Who is this book for?

This book is designed for Python developers at any level of experience with Python programming who want to learn geometric computer modeling, whether they are young, adults, professionals, or teachers. In addition, it is a book designed for beginners or novices in mathematical concepts.

To read this book fluently and get all the potential, we suggest previous fundamental programming elements in Python as variables, loops, functions, arrays, and a basic concept of libraries.

If you need to learn about programming in Python language, we encourage you to read the book *Python For* **Beginners: A Practical and Step-by-Step Guide to Programming with Python**. You can get it at https://www.amazon.com/dp/B0C3FQJ45T/. Sometimes, the digital version of that book is available for free download. If it's not, please email us at practicalbooksco@gmail.com with a screenshot of your Amazon purchase of this book, and we will give you a PDF version of the *Python For Beginners* book for free.

What does this book cover?

As the title indicates, this book is a quick introduction and step-by-step guide to geometric modeling using Python, including parametric curves and surfaces modeling. It is a short book designed not to overwhelm the reader. Although it could have covered more topics, only the topics above are treated to explain them well and in detail.

By the end of the book, the reader will have acquired knowledge of fundamental elements in geometric modeling, which they can then apply in more advanced projects, allowing them to gain new knowledge more easily.

What previous experience do the authors have?

Ronald has a background in mechanical engineering and earned a doctorate in the field of computer science. He is a committed teacher and researcher thanks to his passion for computer engineering; moreover, he has lectured and coordinated the course *Introduction to CAD/CAM System*. On the other hand, Daniel and Paola have more than 18 years of combined experience in teaching programming. They have also been authors of other web programming books. During these years, they taught programming to thousands of university students.

In this book, they compile and present many of the strategies used to teach programming, mechanical engineering, design engineering, interactive design, and computer modeling to different audiences of students.

General comments

If you have any questions about any aspect of this book, please email us at practicalbooksco@gmail.com and mention the book title in the subject line of your message.

Errors in the book (errata)

Although multiple people have reviewed the book, and we have taken all precautions to ensure its quality, errors happen. Therefore, if you find any errors in this book, we ask and appreciate

that you please write to us at practicalbooksco@gmail.com informing us of the error to be corrected.

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Chapter 01 – Introduction

While existing literature on geometric modeling for CAD applications often delves into abstract mathematical concepts like linear algebra, vector spaces, and topology, it may neglect the direct application of these theories to practical problem-solving. This book takes a distinctive approach by prioritizing the resolution of real-world challenges and the development of geometric modeling applications, using a structured and systematic approach. It emphasizes the utilization of fundamental and accessible mathematical concepts, ensuring that you can swiftly grasp the ideas presented and easily apply them. The main objective is to facilitate a direct and efficient learning experience for individuals seeking practical insights into geometric modeling for CAD.

This chapter will explain the book's design and how to use it effectively.

Next, we will cover the following sections:
1. Book chapters.
2. How to read this book.
3. Book repository.

1.1. Book chapters

This book is divided into 16 chapters. Here is a brief overview of what you can expect to learn in each chapter:
- **Chapter 01 – Introduction.** Provides an overview of the book and its contents.
- **Chapter 02 – Geometric Modelling.** Provides the context computational geometric modeling, its significance, and applications across different fields.
- **Chapter 03 – Setting Colab.** Describes how to use Colab, a popular tool for coding in Python.
- **Chapter 04 – Introduction to *NumPy*.** Introduces the *NumPy* library and demonstrates how to operate mathematical expressions.
- **Chapter 05 – Introduction to *Matplotlib*.** Demonstrates how to use *Matplotlib* to create raster images in Python.
- **Chapter 06 – Introduction to *Plotly Express*.** Introduces *Plotly Express* module and demonstrates how to create vectorial graphics in Python.
- **Chapter 07 – Parametric curves in 2D.** Introduces fundamental concepts of parametric curves. It also explains the elements for curves in 3D.
- **Chapter 08 – Parametric curves in 3D.** Extends the concept of parametric curves to 3D
- **Chapter 09 – Parametric surfaces in 2D.** Introduces fundamental concepts of parametric surfaces. It also explains the elements for surfaces in 2D.
- **Chapter 10 – Parametric surfaces in 3D.** Extends the concept of parametric surfaces to 3D.

- **Chapter 11 – Special case: Extruded surfaces.** Develops the concept of parametric extruded surfaces in 3D.
- **Chapter 12 – Special case: Surfaces of revolution.** Develops the concept of parametric surfaces of revolution in 3D.
- **Chapter 13 – Special case: Polar-coordinate surfaces.** Develops the concept of parametric surfaces in 3D based on the polar coordinate system.
- **Chapter 14 – Special case: Complex surfaces.** Develops the concept of surface modeling to a higher level.
- **Chapter 15 – Deploying models to the Cloud.** Develops the concept to deploy your models on the Cloud.
- **Chapter 16 – Exercises solutions.** Contains the answer to the exercises proposed throughout the book.

1.2. How to read this book

To make the most out of this book and improve your understanding of the concepts presented, we recommend following these suggestions:

Read in order

If this is your first time in computational geometric modeling, we recommend reading this book in order. The book is designed to teach different concepts and elements in order. These concepts and elements will be reused in later chapters, which means that, for example, to understand and enjoy "Chapter 12 – Special case: Surfaces of Revolution", you will need to understand almost all previous chapters. For instance, within this chapter, we use various elements such as *parametric surfaces description* introduced in previous chapters.

Learning by doing

One of the key elements of this book is "learning by doing", inspired by one of Daniel and Paola's favorite book authors, Greg Lim. **In this book, you will learn to model by modeling**. We have included over 100 independent pieces of code for you to develop, and we strongly recommend that you code them manually. By doing so, you will acquire modeling skills and better understand each element used. Take the time to read each piece of code, analyze it in detail, and execute it. This approach will help you master the concepts covered in this book.

TIP: Learning by doing: "Human beings are insatiable seekers of knowledge; however, they do not learn what they hear, read, memorize or study... they learn what they practice." (Taken from: *2019 - Samsó, R. - The Power of Discipline: The Habit that will Change your Life*).

Exercises for practice

At the end of most chapters, you will find a set of simple exercises designed to help you reinforce the concepts and skills learned in that chapter. We encourage you to complete these exercises before moving on to the next chapter. Doing so will allow you to test your understanding and ensure you have acquired the expected skills. In addition, you will find the solutions to all the exercises in the book's last chapter.

1.3. Book repository

In most chapters, we will write pieces of code in Python. All code pieces developed in this book can be found in the book repository at the following link: https://github.com/PracticalBooks/Python-For-Geometric-Modeling. If we modify the code later, those modifications will be reflected in the repository.

Questions

If you have any questions or would like to discuss any aspect of this book, we recommend using the discussion area of the book repository, located at https://github.com/PracticalBooks/Python-For-Geometric-Modeling/discussions (see Figure 1-1). This platform allows you to learn from the questions and discussions posted by other readers ①, while also enabling you to seek help and interact with the book's authors and community. With input and contributions from various members, the discussion area can provide a collaborative and enriched learning experience. Please note that you need a GitHub account to access the "New discussion" button ②.
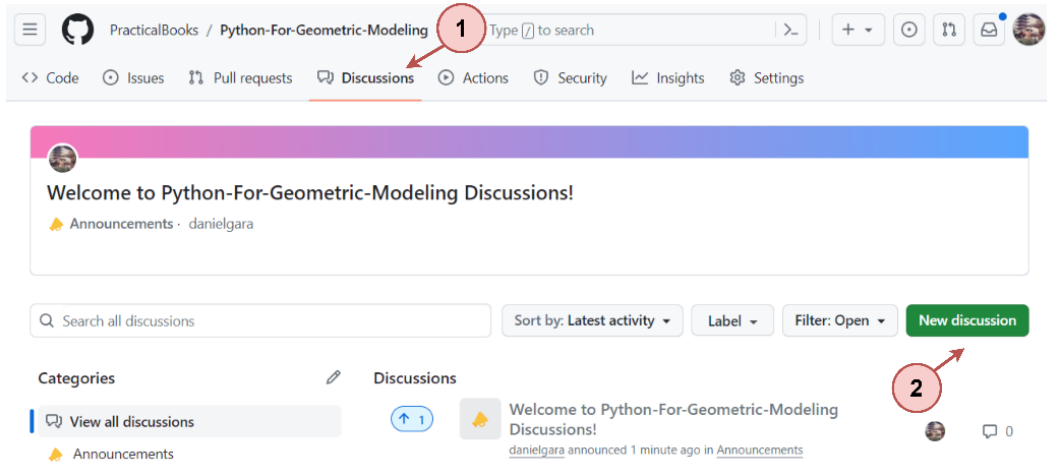
Figure 1-1. Discussion area of the book's repository.

In addition to using the book repository's discussion area, you can email your questions or suggestions to practicalbooksco@gmail.com. Please mention the book title in the subject of the message to be sent.

Summary

This chapter introduced the book, including its structure and essential features created to facilitate reading and learning the elements that will be taught.

Now, let's start our journey to the world of computer geometric modeling!

Chapter 02 – Geometric Modeling

This chapter aims to provide a general understanding of computational geometric modeling, its significance, and its applications across different fields. We introduce practical applications and the impact of geometric modeling on the advancement of technology and innovation.

Next, we will cover the following sections:
1. What is computational geometric modeling?
2. Why is geometric modeling needed?
3. What is geometric computer modeling for?

2.1. What is computational geometric modeling?

Computational geometric modeling is a branch of computer *science* and *mathematics* that uses computational techniques to represent, manipulate, and analyze geometric shapes and structures. Computational geometric modeling plays a crucial role in *computer-aided design* (CAD), computer graphics, virtual reality, and various other fields where the digital representation of physical objects or spaces is required.

Key aspects of computational geometric modeling include (*i*) *representation*: It involves choosing a suitable mathematical representation for geometric objects. Common representations include points, lines, curves, surfaces, and solids; and (*ii*) *parametric modeling*: This involves representing objects using parameters that can be adjusted to modify the shape, which is widely used in CAD systems. Therefore, computational geometric modeling provides the foundation for creating and manipulating digital representations of geometric objects, enabling various applications in computer science and engineering.

2.2. Why is geometric modeling needed?

Computational geometric modeling enhances efficiency, accuracy, and innovation across different industries. It facilitates the entire product development lifecycle, from conceptualization and design to prototyping, testing, and final production. The ability to create and manipulate digital representations of physical objects has become a cornerstone of modern engineering, design, and simulation. Therefore, computational geometric modeling is important for several reasons:
- **Cost Reduction:** The design and testing phases can be optimized, leading to cost savings. Identifying and rectifying issues early in the design process helps prevent costly mistakes in later stages of production.

- **Efficient Communication:** Geometric models serve as a common language for communication among designers, engineers, architects, and other stakeholders. They provide an unambiguous way to convey design concepts and specifications. Moreover, geometric modeling allows designers and engineers to create detailed and accurate digital representations of objects, structures, and environments. It aids in visualization, enabling professionals to assess and refine designs before physical prototypes are built.
- **Prototyping and Testing:** Geometric models are crucial in the prototyping process, allowing for the creation of physical prototypes through techniques like 3D printing. It facilitates testing and validation of designs before mass production.
- **Simulation and Training:** Geometric modeling is used in simulations to analyze and understand the behavior of systems and for training purposes. It is applicable in various fields, including physics, engineering, medicine, and more. For example, flight simulators use detailed geometric models of aircraft and landscapes to provide realistic training scenarios for pilots.

2.3. What is geometric computer modeling for?

Computational geometric modeling is useful in various industries and disciplines, contributing to improved design processes, efficient manufacturing, realistic simulations, and enhanced understanding of complex systems. It serves various purposes across different fields, such as:
- **Computer-Aided Design (CAD):** Geometric modeling is extensively used in CAD systems to create digital representations of physical objects. Engineers and product Designers: Professionals in product design use geometric modeling to create digital representations and visualize concepts for consumer products, structures, appliances, systems, and industrial equipment. It helps in refining designs and ensuring functionality, e.g.:
  - Creation of objects and virtual environments.
  - Modeling and visualization of 3D data.
  - Graphical representation of molecular structures in chemistry and biology.
  - Visualization of geospatial data.
- **Manufacturing and Prototyping:** Computing geometric models are used to create prototypes and simulate manufacturing processes. It helps in identifying potential issues and optimizing the production process before physical prototypes are built, e.g.:
  - Development of 3D models of products prior to manufacturing.
  - Virtual prototyping to evaluate product form and function.
  - Computer-aided design (CAD) for engineering and architecture.
- **Computer graphics Artist/Animator:** Geometric modeling is essential for creating virtual environments, and 3D models of characters and objects. It includes video games, movies, animations, and simulations. Artists and animators use geometric models to define the shape and appearance of 3D objects in these digital media, e.g.:
  - Creation of 3D models for characters, scenery, and objects.

- Character and object animation.
- Design of virtual worlds and interactive environments.
- **Architecture/Civil engineers:** Architects use geometric modeling to design and visualize buildings, structures, roads, bridges, and water systems, in a digital environment before construction begins. It helps in creating detailed plans and virtual models of architectural projects and allows for exploration of design alternatives and identification of potential issues, e.g.:
  - Modeling of buildings and urban landscapes.
  - Architectural visualization for presentations and analysis.
  - Design and planning of construction projects.
- **Virtual Reality (VR) and Augmented Reality (AR):** Geometric models are fundamental in creating immersive virtual and augmented reality experiences. These models allow users to interact with and navigate through simulated environments that represent real-world scenarios, e.g.:
  - Integration of virtual objects in real-world environments.
  - Simulation of physical phenomena for engineering analysis.
  - Training in virtual environments for aviation and military professionals, etc.
- **Medical Imaging:** Geometric modeling is applied in medical imaging to represent and analyze anatomical structures. It includes creating 3D models from medical imaging data such as *CT scans* and *MRI*s. These models can be used for surgical planning, education, and research, e.g.:
  - Modeling of anatomical structures for medical simulations and surgery planning.
  - Design and fabrication of customized prostheses.
  - Medical data visualization in 3D environments.
  - Virtual realism simulations for medical training.
- **Mechanical/Mechatronic Engineer/Robotics:** Mechanical engineers apply geometric modeling for designing and analyzing mechanical components and systems. It is crucial in developing machinery, tools, and other mechanical devices. Geometric models play a crucial role in robotics for path planning and control. Robots rely on accurate geometric representations of their environment to navigate and interact with objects, e.g.:
  - Numerical control of machines for the manufacture of parts and components.
  - Robotics and industrial automation.
  - 3D printing and additive manufacturing.
- **Aerospace Engineer:** Aerospace engineers use geometric modeling to design and analyze aircraft and spacecraft. It is crucial for aerodynamics, structural analysis, and system integration.

Figure 2-1 to Figure 2-6 show some geometric models we will develop through this book. In addition, it is easy to see that Figure 2-1 and Figure 2-2 are useful for aerospace engineering, Figure 2-3 is interesting for video game development, Figure 2-4 can be a framework for product design, Figure 2-5 will be a roof of a restaurant, a modern house or a building for architectural and civil engineering purposes, and Figure 2-6 will represent a material for virtual reality use.
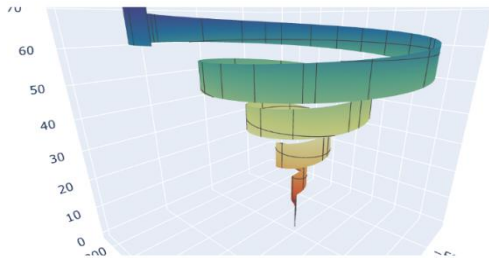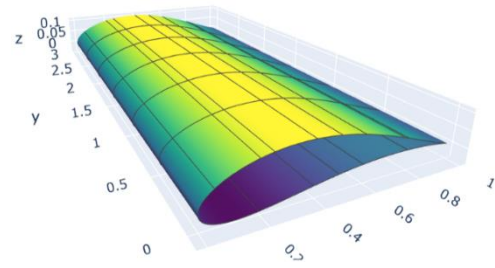

Figure 2-1. Twister band.

Figure 2-2. Aircraft wing.
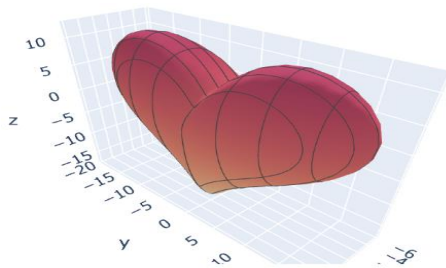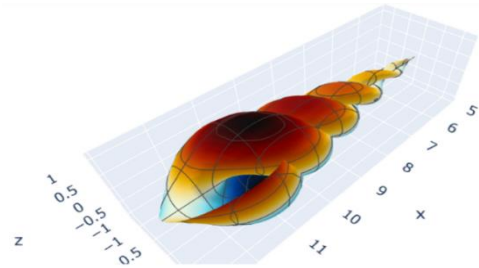

Figure 2-3. Digital heart.
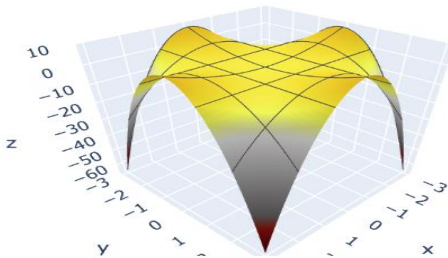

Figure 2-4. Seashell.
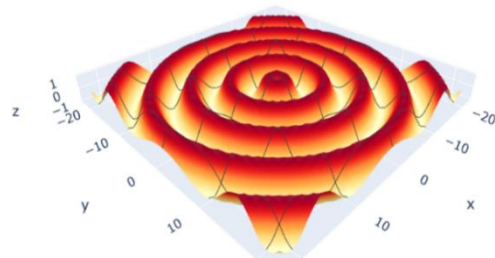

Figure 2-5. Hyperbolic roof.

Figure 2-6. Waves on water's surface.

Computational geometric modeling continues to expand into new fields and professions as technology evolves. The ability to create, manipulate, and analyze digital representations of physical objects is valuable across various industries and professions.

Summary

This chapter has addressed some general concerns about the potential of computational geometric modeling, fields of action, applications, and importance in technological development.

In the next chapter, we will see an easy and agile Python programming platform to develop our models.

You can follow the complete book on
https://lnkd.in/eKAt_m2M