APPLICATIONS OF DIGITAL TRANSFORMATIONS AND SIMULATION MODELING IN AEROSPACE ENGINEERING AND SECURITY

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Abstract: The aim of this experimental research is to present the advantages of advanced methods for digital transformation of objects in order to create accurate engineering models of aerospace objects and radio engineering devices. One of the scientifically applied contributions is expressed in the proposed algorithm for engineering design of a pyramidal horn antenna based on simulation data, realized by 3D modeling techniques for digitalization. The generated results illustrate the correct selection of software products due to their compatibility and capabilities.

Key words: 3D modeling, 3D printing, simulation, digitalization, planar antennas, radio engineering devices, horn antennas, aerospace engineering, security.

1. INTRODUCTION

The topicality of the theme is due to the digital strategy, which *"reduces labor costs and pressure on service prices"*, according to the European Central Bank. In fact, the digital strategy helps to transform the business in a positive direction, building on digitalization through the implementation of innovative technologies, integrated solutions, and process automation.

Applying an integrated approach to the practical implementation of specific types of engineering objects facilitates the timely elimination of potential problems and errors related to the work process since modern CAD/CAM/CAE systems for construction, production, and engineering analysis have modules for performing process simulation and visualization [1], which aim to increase the economic efficiency of the optimization with a view to reducing the time for production and costs.

There are different methods for digital transformation, some of which require a 3D scanner, while others are realized through photographic materials with high resolution from all sides of the object and photogrammetric software products. In practice, precise engineering models suitable for simulation can be built in an engineering 3D modeling product or in the simulation environment itself if it provides sufficient capabilities. There is an abundance of products for 3D modeling, simulation, and visualization, and it depends on the researcher how to apply them in the developed methodology to optimize the processes and reduce the risks of technical problems and errors.

The representation of the study is divided into two sections. Section 2 aims to describe the interrelationships between concepts, emphasizing the means of practical realization of engineering modeling and the role of simulation modeling in the overall process of digital transformation.

Section 3 presents the experimental part of this empirical study, which is expressed in the proposed algorithm for the engineering design of a pyramidal horn antenna by using input data, which are indeed output data obtained by simulation. This algorithm contributes to the design methodology, especially due to the steps related to verifying the data obtained in one software product by the data generated in another simulation software based on a comparative analysis.

2. THE ROLE OF SIMULATION MODELING IN AEROSPACE AND SECURITY STUDIES

In this section, main applications of radio engineering devices (planar and horn antennas) in aerospace engineering and security are represented Some examples of experimental work are given to demonstrate how simulation modeling of antennas and measurements using planar antennas can be applied as successive stages in a comprehensive study. The recent work of the author is related to studying applications of simulation modeling methods in prevention of jamming attacks on communication networks based on investigating different types of antennas [2, 3].

In practice, the need to use several different simulation software products in parallel with experimental studies by physical devices is imposed by the specifics of individual resources and their advantages. For example, some products allow the 3D modeling of the studied simulation model but do not provide the capability for agent-based visualization. For greater clarity, it should be explained in what sequence and for what purpose the various simulation products were used by the author. Therefore, the scheme in Fig. 1 illustrates the sequence of application of the selected products in an overall simulation study as well as their possible roles in it.

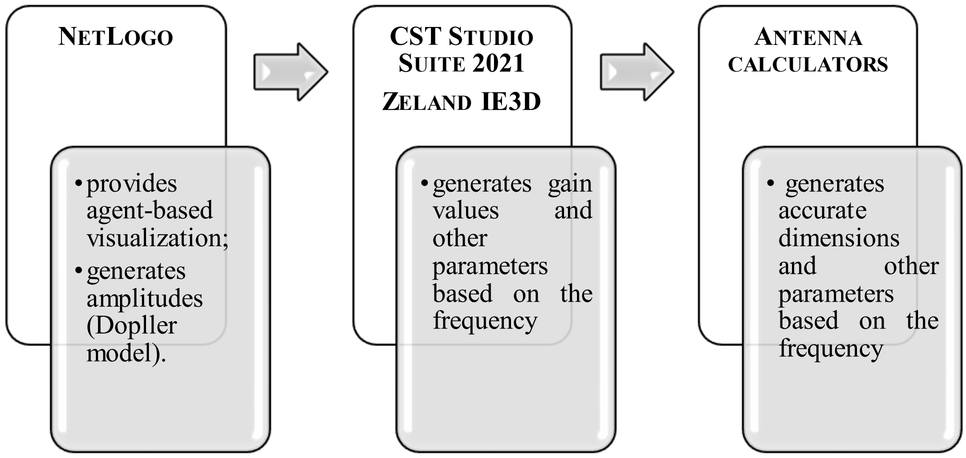

Fig. 1. The sequence of application of the selected products in the overall simulation study

2.1. Applications of radio engineering devices in aerospace engineering and security

The related work in the field of satellite telecommunications and technologies for security starts with measuring the parameters of a planar antenna using the simulation software Zeland IE3D and an experimental installation including physical devices [4]. From the point of view of cybersecurity, a disadvantage of satellite signals is their weakness, which makes them "*vulnerable to radio frequency (RF) interference"* [5]. Planar antennas can be effectively used for security in innovative solutions for preventing jamming attacks by massive planar antenna arrays [6].

This research is devoted to the application of antennas for cybersecurity purposes, and in particular for prevention of jamming attacks. These experimental studies are realized in two simulation environments: Riverbed Modeler Academic Edition 17.5 is used for studying the impact of DoS (Denial-of-Service) attacks realized by jammers, and CST Studio Suite 2021 is used for a simulation of horn antennas to consider the risks of using them for jamming.

Table 1 includes summary data for these empirical studies. "*G"* is the gain measured using SWR meter type 241, which is connected to the receiving antenna A_r. There are two types of receiving antennas that can be used for the experiment: a standard square patch antenna (A_r) and a receiving circular antenna (A_{rc}). The abbreviation "rc" in the subscript consists of the first letters of "receiving" and "circular". In the last column of Table 1, the value "Dir." denotes the maximum power that the horn antenna can transmit or receive in a certain direction. The transmitting antenna A_t is powered by a high-frequency signal generator „Г4-79".

Table 1.

Research method	***Devices***	***Resources***	***f, GHz***	***G, dB/ Dir., dBi***
The three-antenna method	Planar antennas	A_r – receiving antenna	2.45	5.72 dB
		A_t – transmitting antenna	2.45	15.77 dB
		A_{rc} – receiving circular antenna	2.45	16.26 dB
Simulation modeling method	Planar antenna	Zeland IE3D	2.45	22 dB
	Pyramidal horn antenna	CST Studio Suite 2021	8	12.51 dBi
			9	13.35 dBi

The results of the gain measurement by the three-antenna method using physical devices are presented in Table 2, where *r* is the distance between the antennas A_r and A_t, shown in Fig. 2, P_r is the received absolute power, and P_t is the transmitted power. To clarify the experiment in detail, the main dimensions of the planar antennas A_r and A_t are given in Table 3.

Table 2.

Antennas	***f, GHz***	***r, cm***	***P_r, dB***	***P_t, dB***	***Gr+Gt, dB***
A_r - A_t	2.45	14.5	0	12.5	10.95
A_t -A_{rc}	2.45	40	0	16.5	15.77
A_r -A_{rc}	2.45	40	0	16	16.26

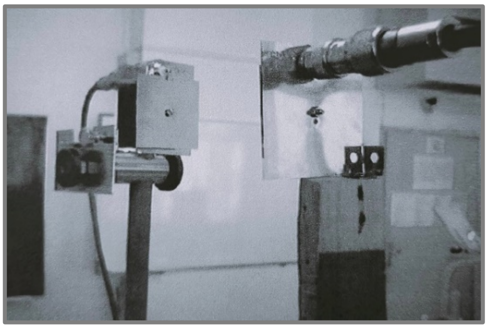

Fig. 2. The receiving and transmitting planar antennas used in the experimental installation.

Table 3.

Antennas	***Shape***	***Material***	***Side length, mm***	***Hight, mm***
A_r	Square	Metalized Dielectric	54	14
A_t	Square	Metalized Dielectric	52	14

The pyramidal horn antenna is chosen for the current study too because, as an appropriate radio engineering device, it is a key component of telecommunication satellites for transmitting radio waves into space, and respectively, belongs to aerospace equipment due to its ability to operate at high frequencies and physical robustness [7].

2.2. A simulation of an airborne pulse Doppler radar

In the security field, high-gain horn antennas are used as components of radar systems. In fact, airborne pulse-Doppler radars detect moving targets [8]. The Doppler effect can be simulated in NetLogo 6.3.0 [9] by one of the models in the embedded library (*"Doppler")* that *"demonstrates the Doppler effect, the apparent change in the frequency of a wave emitted by a source moving relative to an observer"* [10]. The agents in this simulation model are a plane and an observer. Its concept can be explained briefly as follows: *"when the source of a wave moves towards you, the perceived frequency of the wave increases; when the source moves away from you, the perceived frequency decreases".*

The agent-based visualization is shown in Fig. 3. The maximum and minimum values of the amplitude for a time period T = 60 s are visible in the diagrams of Fig. 4. For example, this simulation model can be used for the calculation of frequencies by the fundamental formula $f = 1/T$, and the calculated values could be inserted as input parameters in other simulation products for obtaining the gain of jamming antennas during studying the impact of jamming attacks for the purpose of better prevention.

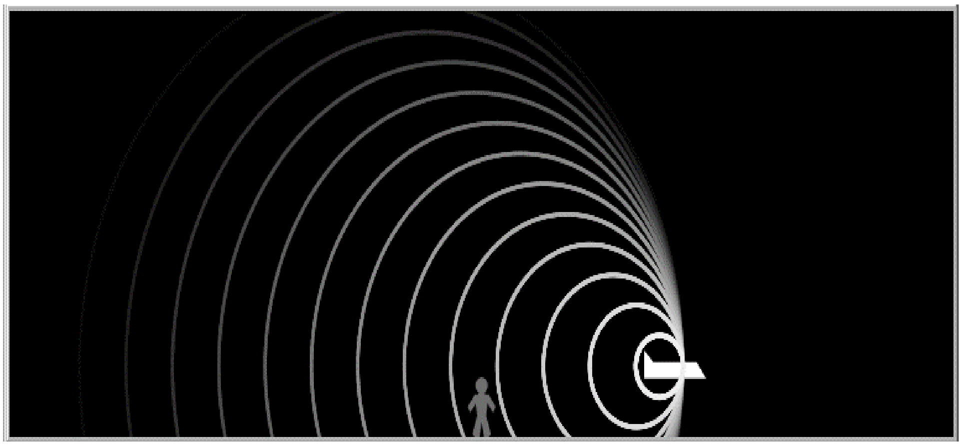

Fig. 3. A Doppler effect simulation in NetLogo 6.3.0.

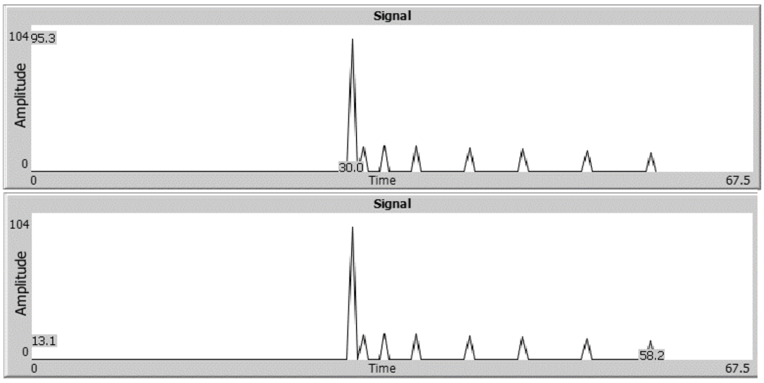

Fig. 4. The maximum and minimum values of the amplitude for an interval of 60 s.

3. AN ALGORITHM FOR THE ENGINEERING DESIGN OF A PYRAMIDAL HORN ANTENNA

The complete process of engineering design is presented in the proposed algorithm in Fig. 5, describing a methodology of three main steps that will be considered in detail further on in this section.

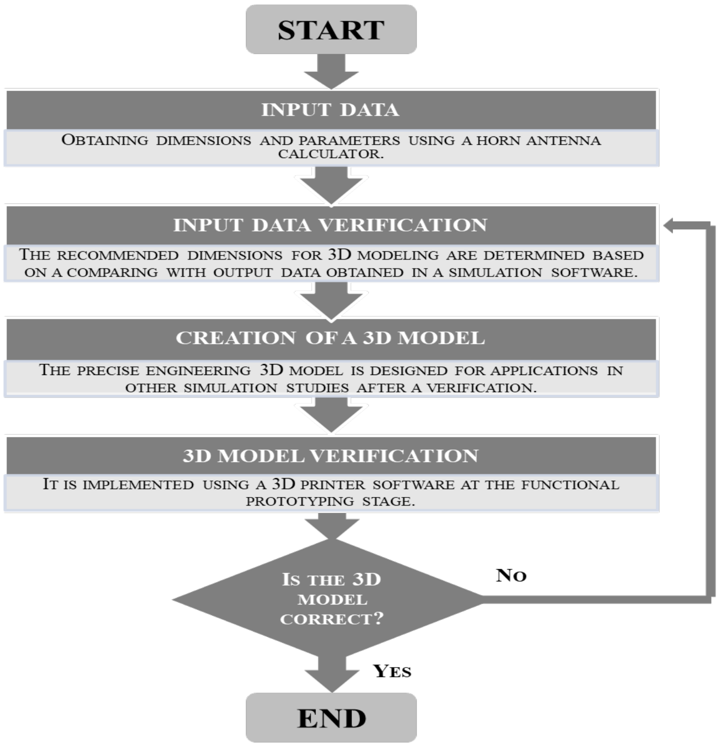

Fig. 5. An algorithm for engineering design of a pyramidal horn antenna.

3.1. Calculation of the pyramidal horn antenna parameters

In this case, the frequencies are chosen to be the same as in the previous simulation of a horn antenna using CST Studio Suite 2021: 8 and 9 GHz. The engineering drawing of the antenna is shown in Fig. 6. In Fig. 7 and Fig. 8, screenshots from the Horn antenna calculator [11] are shown. The author designed the antenna in the software Autodesk 123D Design for both cases based on the „*waveguide dimensions*" and the horn length R, horn wide plane length D_1, horn narrow plane length D_2, and horn aperture dimensions A_p and B_p generated in the calculator, which are presented in Table 4.

Table 4.

	Waveguide dimensions			***Horn wide/narrow plane length***			***Horn aperture dimensions***		***Exciting pin height***
f, GHz	***a, mm***	***b, mm***	***c, mm***	***D_1, mm***	***D_2, mm***	***R, mm***	***A_p, mm***	***B_p, mm***	***h, mm***
8	28.1	14.1	31.7	22.7	24.8	18.3	61.5	41	8.2
9	25	12.5	28.2	20.2	22	16.3	54.7	36.5	7.3

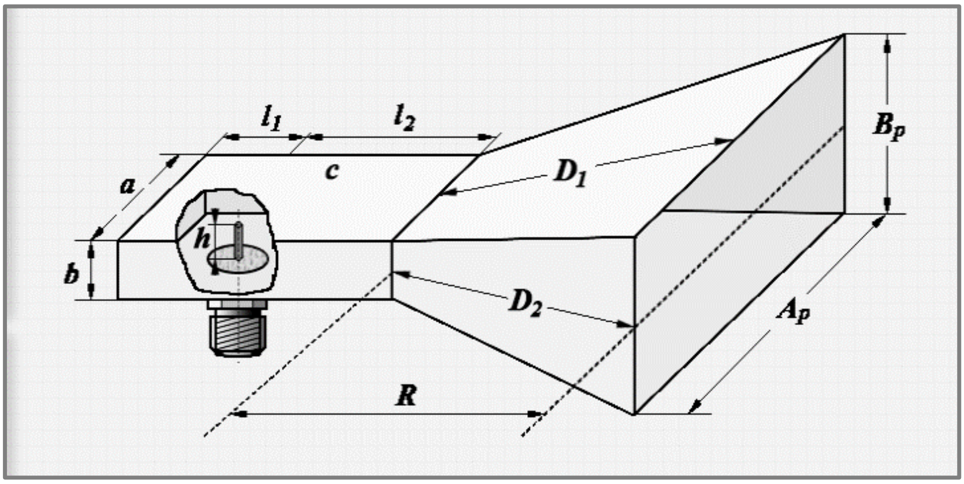

Fig. 6. The pyramidal horn antenna engineering drawing.

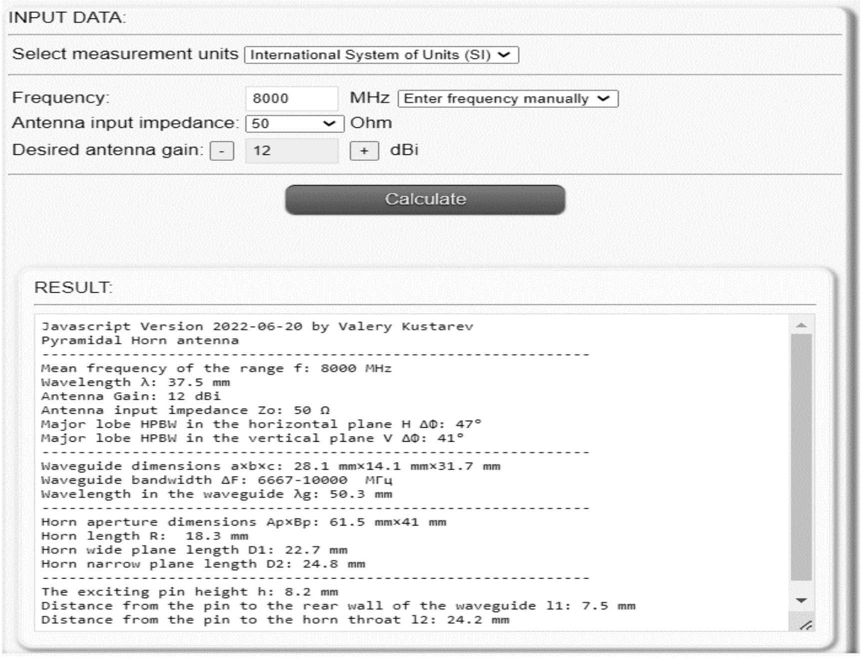

Fig. 7. The horn antenna parameters at a frequency of 8 GHz.

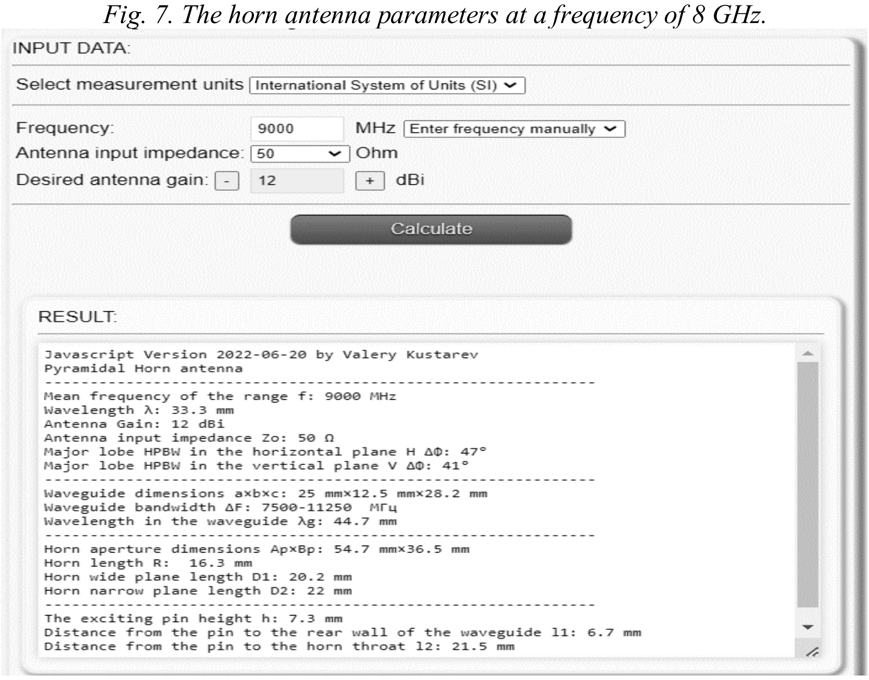

Fig. 8. The horn antenna parameters at a frequency of 9 GHz.

3.2. 3D modeling of a pyramidal horn antenna in Autodesk 123D Design

The 3D model of the pyramidal horn antenna is created using the software Autodesk 123D Design based on the dimensions in Fig. 7 at a frequency of 8 GHz, because of its high accuracy. In Figs. 9 and 10, screenshots taken during the designing process are presented in order to illustrate the product's capabilities for precision engineering modeling.

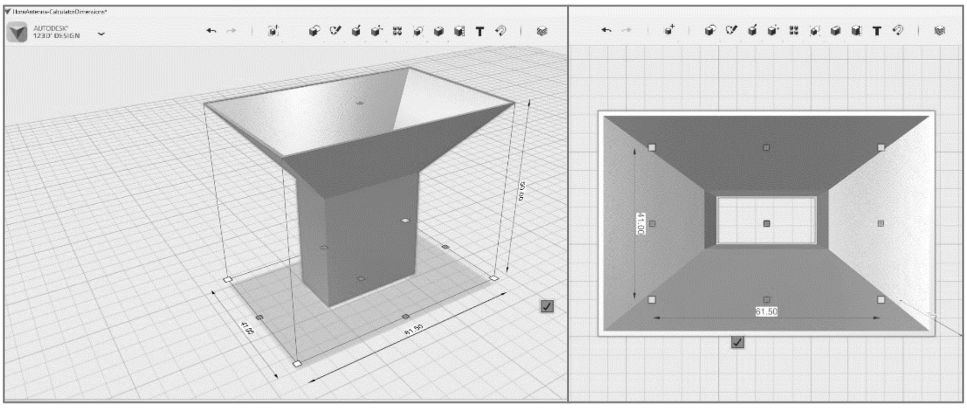

Fig. 9. The 3D model of a pyramidal horn antenna in perspective and top view.

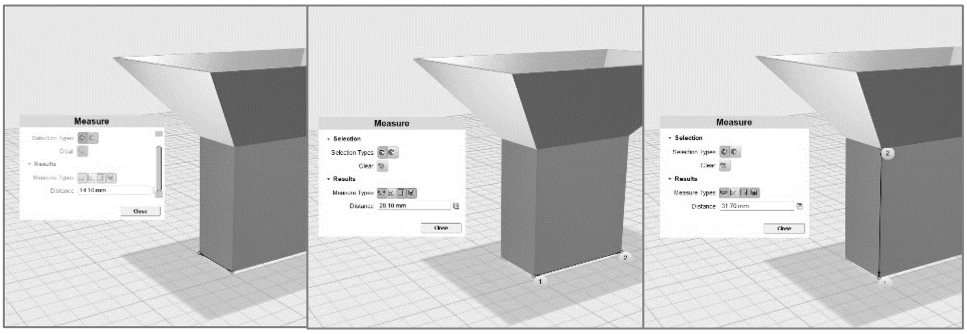

Fig. 10. The “Measure” tool is used to check the dimensional accuracy of the 3D model.

3.3. Assessment and analysis of the simulation results

To verify the results from the calculator, the author compared them to the simulation results generated in CST Studio Suite 2021. The calculation results are summarized in Table 5. It can be concluded that the gain values generated in scenarios 1 and 2 in both products are satisfying because they are in the same range (12-14 dBi).

Table 5.

		CST Studio Suite 2021	***Horn antenna calculator***
Scenarios	***f, GHz***	***G, dBi***	***G, dBi***
Scenario 1	***8***	12.51	12
Scenario 2	***9***	13.35	12

The 3D model is verified by the software *XYZprint* during the preparation process before 3D printing using a 3D printer *da Vinci mini w+ or Creality Ender3 V2*. If there are any errors or problems in the 3D model, the software of the printer detects them at the beginning. The 3D-printed device is suitable for a functional prototype for conducting tests before mechanical machine production because PLA (Polylactic acid) and PETG (Polyethylene terephthalate glycol) filaments are characterized by very good quality and resistance.

The screenshot shown in Fig. 11 proves that the object is designed precisely and according to the recommended settings summarized in Table 6, which means that the digital transformation by the method of 3D modeling using the simulation data leads to satisfactory results and could contribute to other experimental studies. Photos of a functional prototype printed from a white PLA filament using Creality Ender3 V2 are also shown in Fig.11.

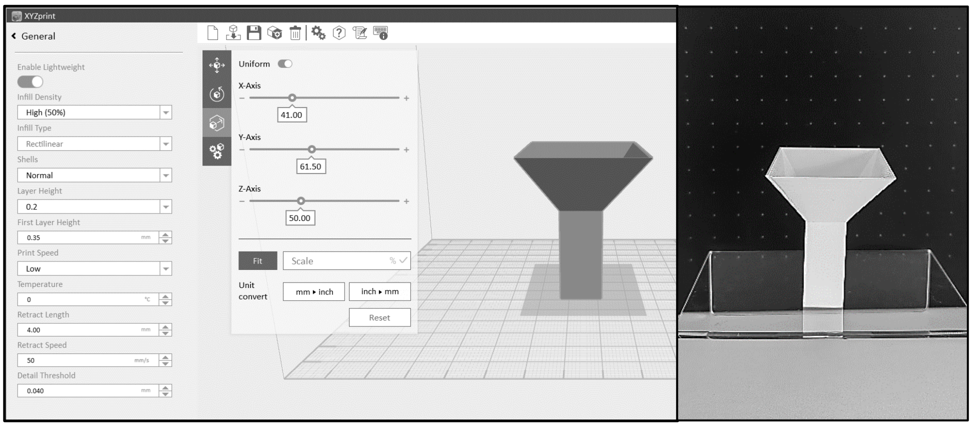

Fig. 11. The verification of the 3D model in the software of the 3D printer, XYZprint, and a photo of the printed antenna.

Table 6.

Settings in XYZprint	***Resolution***	***High Infill Density, %***	***Layer Height, mm***	***Print Speed***
	High Detail	50	0.2	Low

4. CONCLUSION

In conclusion, it can be said that simulation modeling and digital transformations are mutually complementary and suitable for joint application in engineering design. Regarding the great variety of software for 3D and simulation modeling, it can only be an advantage for conducting detailed and in-depth experimental research due to better possibilities for verification and validation of models, optimization of processes, and reducing costs.

Actually, this paper is a presentation of one of the methods of conducting research for the purposes of aerospace engineering and security. The study could be continued by testing the 3D-modeled devices in different simulation environments in order to make comparative analyses that could contribute to improving and optimizing design techniques. In this sense, the metalized 3D-printed antenna can be used to measure the gain in a physical environment using real devices.

Furthermore, the methods and techniques proposed can be implemented in other fields like medical sciences and bioengineering to improve disease analysis [12]. Last but not least, simulations can be run *"under conditions similar to monitoring"* to make the obtained results comparable [13].

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