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Tiffany Hatzidimitriu

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Name: Tiffany Hatzidimitriu

B.A. in Computer Science

Advisor: Dr. Carmine Guida

Sceidenberg School of Computer Science and Information Systems

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Abstract

The Antikythera mechanism is the oldest known analogue computer. Discovered off the coast of the Greek island of Antikythera, the Antikythera mechanism predicts and displays the position of astronomical bodies as well as astronomical phenomena. Due to its complexity, visualization of the gears movement can be very difficult. For my project I created an interactive Augmented Reality (AR) model of the Antikythera mechanism using Unity game engine. I hope this AR application exposes people to the Antikythera mechanism and its inner workings.

Table of Contents

List of Figures

Introduction

In this paper, I will explain the process of making an animated, augmented reality (AR) model of the Antikythera mechanism. The Antikythera mechanism is the earliest known analogue computer [1]. Discovered in 1900 by sponge divers, the fragmented mechanism was found to be an astronomical calculator. Research into the mysteries of the machine is ongoing and interdisciplinary, including but not limited to: archaeological dating, decipherment, modeling, and digital imaging [2]. The original mechanism was corroded into fragments with all the original wood gone leaving only a third of the original bronze gear wheels, all of which are currently housed in the National Archeological Museum in Athens alongside multiple replicas and reconstructions. Each reconstruction building upon new research of previous discoveries and theories [3]. The creation of the Antikythera Mechanism Research Project (AMRP) by Tony Freeth in 2000 sparked renewed interest in the mechanism. The AMRP provides a repository of Antikythera mechanism research but provides few resources other than articles to foster deeper insight into the workings of the mechanism. Animated computer aided design (CAD) models have been created by researchers, but they are not often not made public nor easily accessible.

In 2008, Micheal T. Wright created a physical reconstruction of the Antikythera machine and videos of his model are available online [4]. Through his videos and speeches, Wright provides great insight into the workings of the mechanism, though the insight is limited to the more complex parts of the mechanism, primarily the lunar gears. In 2012, Fivos Asimakopoulos and Dr. Manos Roumeliotis created a simulation of the Antikythera machine in C++ [5]. The simulation is extremely impressive; however, it is over ten years old and difficult to interface with. For my thesis, I decided to create a simulation using contemporary technology, specifiallt CAD and AR. As a Greek American and Computer Science student, I felt it necessary to create an interactive and accessible model of the Antikythera mechanism as a way of raising awareness towards its existence, importance and configuration.

Literature Review

History of the Mechanism

In 1900, sponge divers diving off the coast of Antikythera, a small island across from Kythera and named as such, found an ancient shipwreck, believed to have sunk between 80-60 BCE. In 1902 German philologist Albert Rehm and archeologist Valerios Stais separately discovered that a previously unidentified lump of bronze was in fact an astrological calculator, though this theory was believed to be anachronistic. Scientist Dereck J. de Solla Price continued research into the mechanism in 1951 and proved it was in fact an astronomical calculator. More research on the mechanism has since been conducted including radiographs and x-ray scans of the artifact, resulting in numerous theoretical models as listed in the introduction [1].

The mechanism consists of seven surviving fragments and thirty surviving gears, including a hand cranked handle that "powers" the mechanism. The mechanism is believed to have 82 gears in total. The gear mechanism was encased in a rectangular wooden box with the front and back faces opening to reveal two calendars that depict and predict astrological phenomena as seen in Figure 1.

Figure 1. Computer generated recreation of Antikythera mechanism (presumed) as seen in [3, p. 3]

The front face depicts a mechanical orrery with the planetary bodies that were known at that time: the Moon, Sun, Mercury, Venus, Mars, Jupiter and Saturn. The orrery face also has a dial for the current date. The planet dials point to which zodiac constellation along the ecliptic the planet is located and where it would be in the ancient Egyptian calendar. The back face has two large dials and three smaller dials. The upper large dial depicts the Metonic cycle, a cycle of approximately nineteen years when the phases of the moon reoccur at the same days of the year. Within the Metonic dial is the Callippic cycle dial to the left and the Olympic dial to the right. The Callippic cycle indicates when the next new moon will take place after an eclipse. The Olympic dial indicates when different ancient Greek games would begin. The bottom large dial depicts the Saros series which predicts solar and lunar eclipses down to the hour. The Exeligmos dial is within the Saros dial and predicts successive eclipses with similar properties in similar locations. [6]. Additionally, each face is covered by a door that contains a brass plate with instructions engraved on it [7].

The astronomical cycles on the mechanism come from Babylonian astronomy. Astronomers in Mesopotania had recorded astronomical and astrological phenomena since 2200 BCE and noticed cycles such as the Metonic and Saros cycles. Greek astronomers analyzed Babylonian data and developed their own astronomical principals. Due to the dating system of the dial calendars and details in the inscriptions of the mechanism, and pottery found in the wreck, the mechanism was believed to have been built in a Corinthian colony, particularly the Corinthian colony of Syracuse in Sicily which happens to have been the home of the famous astronomer and mathematician, Archimedes [7].

The Antikythera mechanism is often referred to as one of the first analog computers [8][9]. This title can be controversial depending on semantics. If a “computer” is something that takes an input, processes it and produces an output, then the Antikythera mechanism is a computer because it computes an outcome. This, however, is not the common contemporary use of the word “computer”. Today, “computer” is synonymous with general-purpose, programmable computers, of which the Antikythera mechanism is not. The Antikythera mechanism received the title “analog computer” since it takes variable physical inputs as opposed to binary, digital inputs, and it contains a differential gear. Despite the semantics of its title, the Antikythera mechanism is considered one of the earliest precursors to the modern day computer and a groundbreaking discovery that reshaped the common perception of the capability of ancient civilizations. Price says in [9] that prior to his research on the Antikythera mechanism, such technology was not thought to be capable since it was unable to withstand the test of time. Today the Kotsanas Museum of Ancient Greek Technology in Athens, Greece houses multiple reconstructions of ancient machines and technologies created in Greece before the common era, including a model and explanation of the Antikythera mechanism [10].

During his reconstruction, Wright found that in order for data to support the function, the lunar gear would need to be differential [4]. The existence of differential gears on the Antikythera machine makes it the earliest mechanism that uses differentials and the first analog computer. Another early example of a device that uses a differential is the South-pointing Chariot. The chariot was a navigational aid that used a differential gear to keep the statue atop the chariot pointing in the same direction no matter which way the chariot was turned [11].

Augmented Reality

Wearable computing is the practice of creating and using computational or sensory devices on one's person [12]. Wearable technology is often used for extended reality. EXtended Reality (XR) is the umbrella term for immersive technologies such as Virtual Reality (VR) and Augmented Reality (AR). VR is a technologically enabled simulated experience designed to give the user an immersive experience. VR commonly uses wearable headgear for a near-eye 3D display. AR can be considered an extension of VR that implements video processing and computer vision techniques [13]. AR has the benefit of building upon reality, while VR attempts to create a new reality. Thus, AR requires less power than VR. AR can be experienced through handheld displays, such as smartphones, which come pre-equipped with the CPUs, cameras, GPUS's, and solid-state compasses which are necessary for AR [12]. The social acceptability of smartphones makes it easy for users to interact with the device and the availability, or popularity, of smartphones means interacting with an AR model requires a lower barrier of entry.

There exists a precedent of using AR to reconstruct ancient ruins, so using AR to reconstruct the Antikythera mechanism is a natural progression within AR research and history education [12]. One such use case is an AR ax head presented in [13]. The ax head would likely sit on a pedestal or behind glass in a physical museum, but in a virtual environment, users have the luxury of being able to examine the object up close and from all sides, and with the camera visualization of AR, users can get a better sense of scale by comparing the artifact to their surroundings. Users can more easily acquire information through the inherent interactivity of AR as seen in Figure 2.

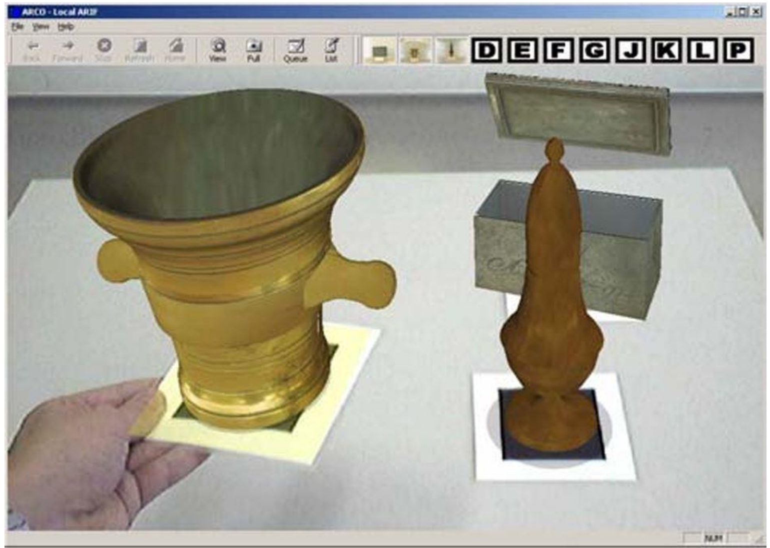

Figure 2: Real scene augmented with superimposed virtual models as seen in [13, p. 187]

Another common use of AR is for recreating complex physical models. In [14], Hasan et al. create an AR controller, 3D model and digital twin of construction machinery. The digital twin in [14] not only mimics the movement of the machine but is directly linked to the physical machine and receives feedback from the machine. The Cyber-Physical system needed a web-based GUI, modular visual programming, compatibility with industry standard mobile applications and more. The digital twin was imported into Unity3D so data of the machine's movement would be directly reflected in the movement of the 3D model.

The digitization of the machinery in [14] is made to help construction workers better interface with their technology; however, these models would not help an average person understand them. Hyundai Motor Company created an AR user manual for the Hyundai Sonata [16]. The AR manual runs on iOS or Android smartphones and uses the smartphone's camera to display where different parts of the car are located on the Hyundai Sonata. Each part is linked to videos of how the part works and what kind of maintenance it would require. Since the Antikythera mechanism uses complex systems of gears that can be difficult to conceptualize through literature, my goal with this project is to facilitate the conceptualization of the Antikythera machine through the medium of technology. In short: I want to make the resource I wish I had.

Process

For this project, I took a pre-existing computer aided design (CAD) model of the Antikythera mechanism, based on Tony Freeth and Alexander Jones' 2012 model, as seen in Figure 2, [8], and animated it using the Unity game engine. Though not the most up to date model, more recent CAD constructions have not yet been made publicly accessible.

Figure 3: Computer generated recreation of Antikythera mechanism (presumed) as seen in [8, p. 37]

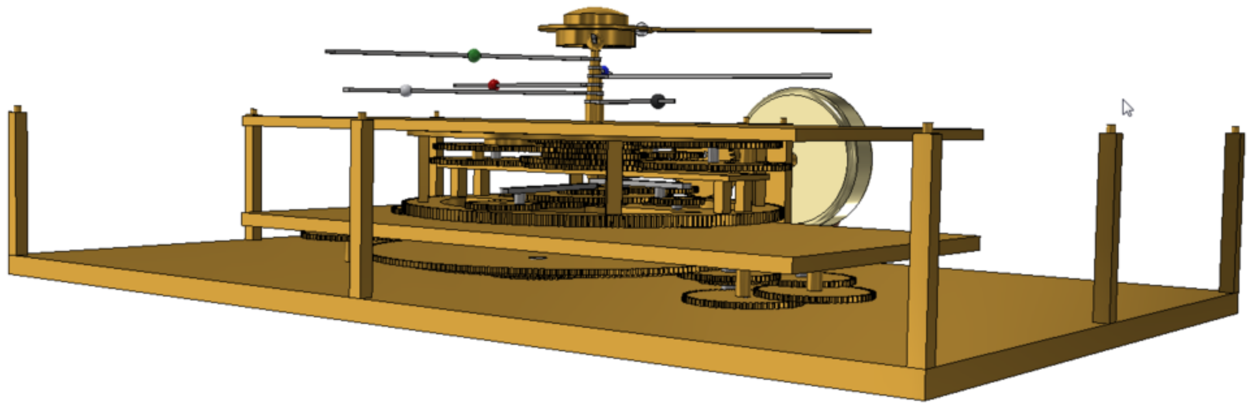

Figure 4: Computer generated recreation of Antikythera mechanism (presumed) (stripped) [16]

The CAD model was uploaded to Unity as one object (.obj file) containing over 191 solid game objects. Most of the redundant objects were removed as well as support structures and the exterior box the gears are encased in. The gears were renamed and organized hierarchically depending on which gear was the dominant gear. Each gear was gives a C# script used to animate the gear to rotate in the appropriate direction at the appropriate speed relative to its surrounding gears. Meshed gears calculate the gear ratio and calculate the speed, measured in degrees per second, accordingly. Compound gears that share an axle move at the same speed. Approximately one third of the mechanism uses simple meshed/compounded gear trains, while most of the planetary gears use pin-and-slot gearing and eccentric rotation. Most gears are given the same script since, algorithmically, the Antikythera mechanism is closest to a dependency graph and each gear (node) has the same features: speed, size, and direction.

Gears e5, e6, k1, and k2 are the lunar gears. K2 rotates on an askew, eccentric axle from k1's axle and is propelled by a pin on k1. The eccentric axle creates an elliptical rotation and the pin propelling k2 causes a variable speed that is meant to match the variable speed of the moon between perigee, when the moon is closest to earth, and apogee, when the moon is farthest from earth. The variable motion of k2 can be calculated using the formula: $\omega_2 = \omega_1 + \varepsilon\omega_1 \cos \omega_1 t$

where ω_2 is the angular velocity of k2, ω_1 is the angular velocity of k1, ε is the eccentricity calculated at 1.1/1.9 and t is time [17]. The variable motion of k2 was hardwired into the C# script. The variable speed script was added to all eccentric compound gears.

The plates are displayed on the front face with a needle pointing to where along the ecliptic the planet is. Within the mechanism, the needle is attached to a crankshaft that rotates the planet needle according to the position of a pin on a gear. I was unable to make the planet needles rotate relative to the pin's global position. The pin's and gear's rotation is relative to itself so the rotation angle cannot be passed and translated to the needle. I attempted handcode the needle's rotation using a sinosidual equation. This also did not work because it didn't match the pin's rotation visually and adjusting period, amplitude and frequency had no effect. Another issue occurred with the moon gears. Due to the orientation of the lun5 gear I was unable to make it rotate appropriately. It revolves at the same degrees per second as the k2 gear, but does not change phases visually as it is supposed to.

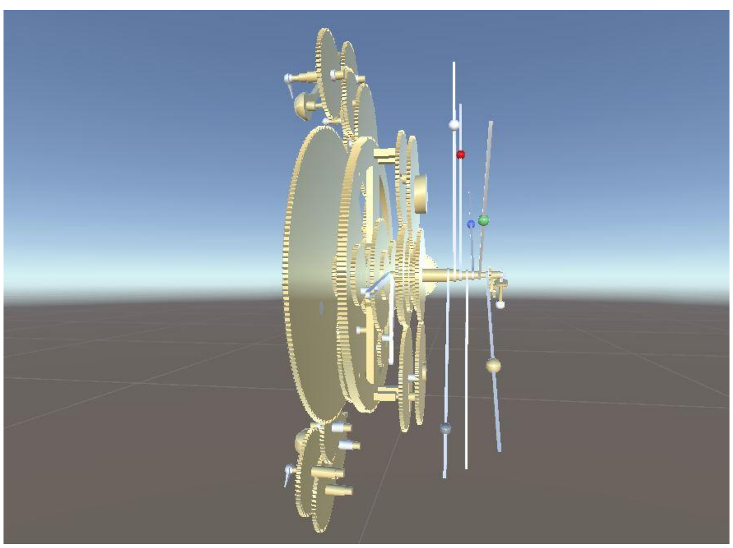

Figure 5: CAD model of Antikythera mechanism in Unity game environment

I converted the now animated model into a prefab and converted the game environment into an AR environment. A prefab is a saved object that can be placed multiple times and edits will apply to all prefabs simultaneously instead of changing each individually. Plane detection scripts were added to the environment to detect horizontal surfaces and place the animated Antikythera mechanism with the correct orientation on the surface. A “Toggle Faces” button was added to the bottom right hand side of the screen that adds/removes the faces so the gears are more visible. Since Unity AR sessions use GPS to orient the position of the placed prefabs, we noticed the prefabs would get lost and the program would have to be restarted so a “Reload” button was added that restarted the program.

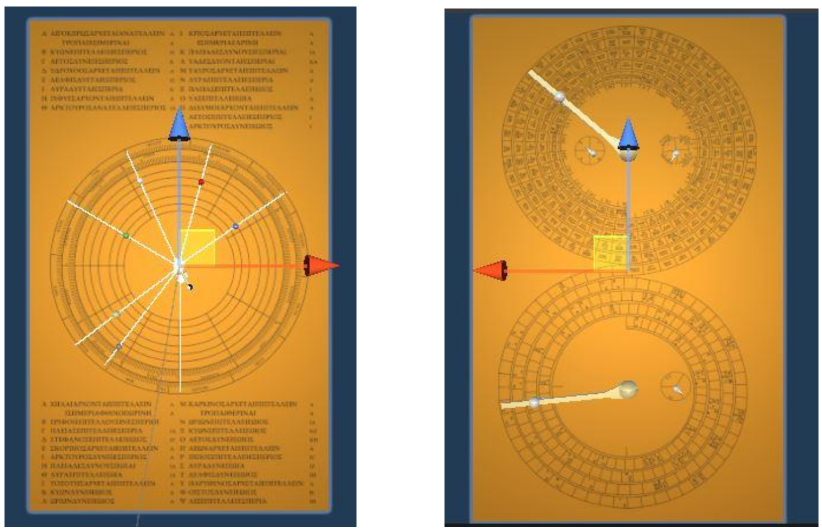

Figure 6: Front and back faces of Antikythera model in prefab mode

I added a slider that adjusts the speed of the models rotation by changing the Delta.time function, which is how the speed of the gears is calculated. The slider is placed on the right hand side along with the toggle button so they will be easily accessible to the largest number of people. A help button was added to the top left corner with a short explanation of what the mechanism is and how the application works. The position and scale were adjusted so the model was on top of the marker, not through the marker and the scale was adjusted so the model was closer to the actual size of the Antikythera mechanism (approximatly 13 inches tall [1]).

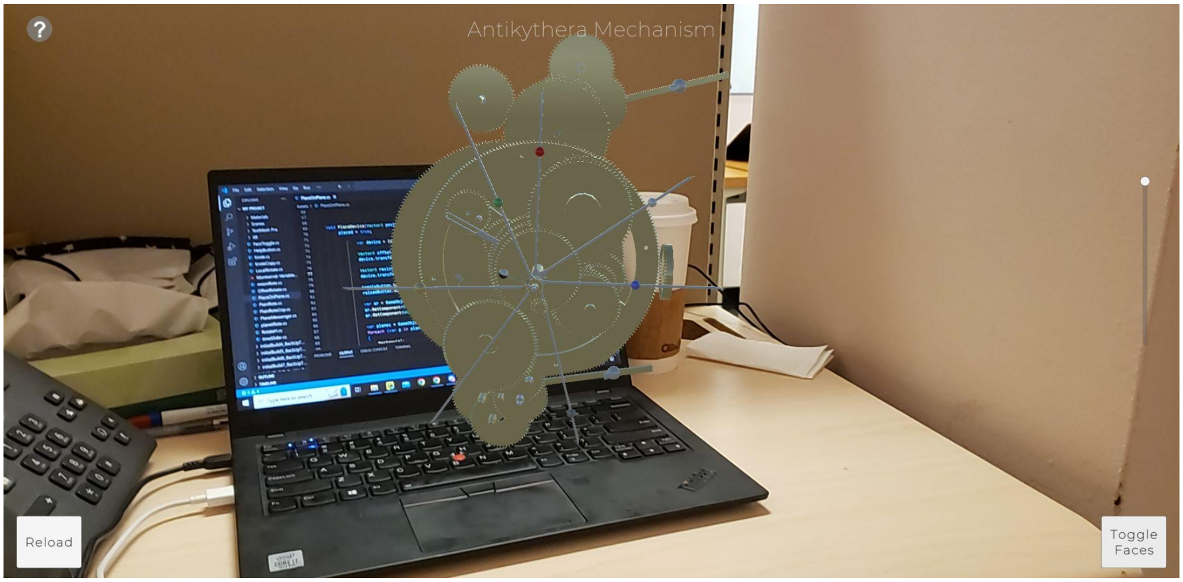

Figure 7: Antikythera model sitting on laptop open with model's source code

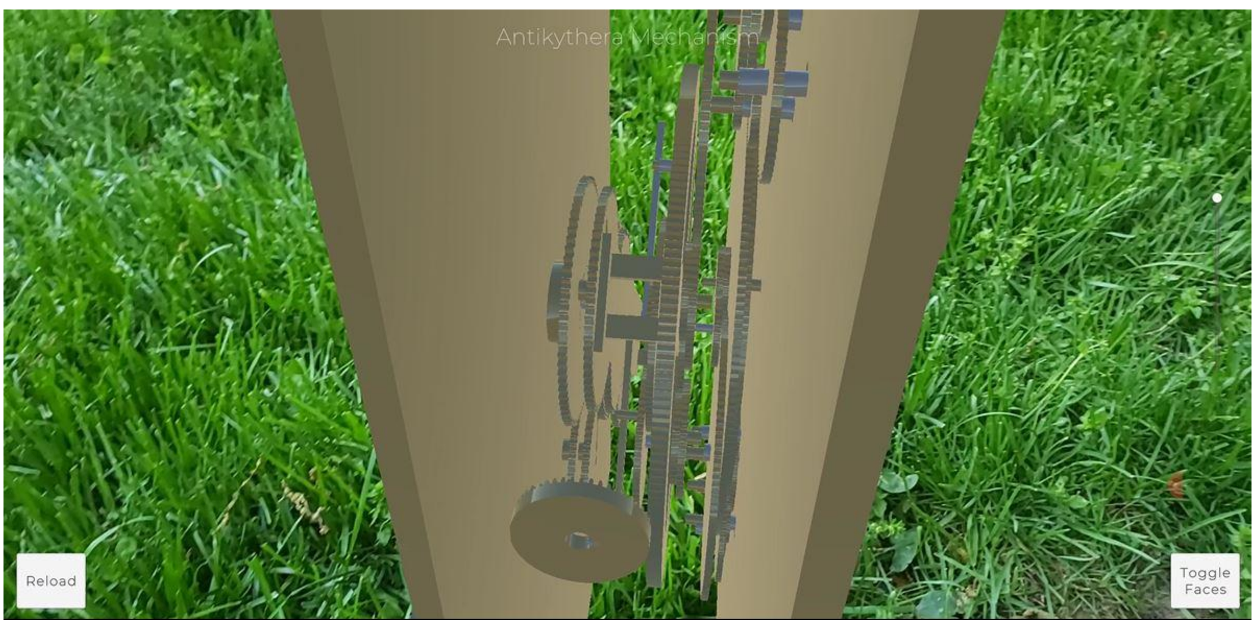

Figure 8: Antikythera model from the side on grass (sans help button)

Conclusion

I was limited by time and the boundaries of Unity's software. Unity's AR engine can be built directly on Google products, but not directy to iOS products so no iOS version was made. I was also limited by using a pre-existing CAD model that I, personally, was unable to alter. In subsequent research I would make my own CAD model that is centered appropriately and I would attempt to use the rigidbody feature in Unity. The rigidbody feature would allow me to apply physics to the game objects directly. I think using rigidbodies would have alleviated the hardcoding necessary to make the gears move and potentially sped up the process. In an attemp to optimize the model some of the files were corrupted and non centered gears began to float away. Under different circumstances I believe a more successful model could have been created, though I do feel I succeeded in what I had set out to do.

References

1. M. Edmunds and T. Freeth, "Using Computation to Decode the First Known Computer," in Computer, vol. 44, no. 7, pp. 32-39, July 2011, doi: 10.1109/MC.2011.134.
2. "Publications." The Antikythera Mechanism Research Project. http://www.antikythera-mechanism.gr/project/publications (accessed Nov. 8th 2022)
3. "'The Antikythera Shipwreck: The ship - the treasures - the Mechanism' - National Archaeological Museum," *National Archaeological Museum*, Dec. 13, 2018. https://www.namuseum.gr/en/temporary_exhibition/to-nayagio-ton-antikythiron-to-ploio-oi-thisayroi-o-michanismos/ (accessed Feb. 09, 2023).
4. M.T. Wright. (2002)"Antikythera Mechanism Working Model" https://www.youtube.com/watch?v=4eUibFQKJqI
5. "HOME PAGE OF MANOS ROUMELIOTIS," *Etl.uom.gr*, 2017. http://www.etl.uom.gr/mr/index.php?mypage=antikythera_sim (accessed Feb. 09, 2023).
6. T. Freeth, D. Higgon, A. Dacanalis, L. MacDonald, M. Georgakopoulou, and A. Wojcik, "A Model of the Cosmos in the ancient Greek Antikythera Mechanism," *Scientific Reports*, vol. 11, no. 1, Mar. 2021, doi: https://doi.org/10.1038/s41598-021-84310-w.
7. Beckham, M. (2012). Star Clock BC: Antikythera Mechanism. Retrieved from https://www.youtube.com/watch?v=SH1cdgvCVZw
8. T. Freeth and A. Jones, "The cosmos in the antikythera mechanism - new york university." [Online]. Available: https://dlib.nyu.edu/awdl/isaw/isaw-papers/4 /. [Accessed: 08-Nov-2022].
9. Derek de Solla Price, 'Gears from the Greeks: The Antikythera Mechanism – a Calendar Computer from ca. 80 B.C.', Transactions of the American Philosophical Society,

Volume 64 Issue7 1974. Reprinted as an independent monograph, New York: Science History Publications, 1975

10. "KOTSANAS MUSEUM | ΜΟΥΣΕΙΟ," Kotsanasmuseum.com, 2014. https://kotsanasmuseum.com/mouseio/ (accessed May 03, 2023).
11. "South-pointing carriage (chariot)," Ucsb.edu, 2023. https://web.physics.ucsb.edu/~lecturedemonstrations/Composer/Pages/92.36.html (accessed May 03, 2023).
12. "Wearable Computing," *The Interaction Design Foundation*, 2022. https://www.interaction-design.org/literature/book/the-encyclopedia-of-human-computer-interaction-2nd-ed/wearable-computing (accessed Feb. 05, 2023).
13. Wojceichowski, R., Walczak, K., White, M., & Cellary, W. (2004). Building Virtual and Augmented Reality Museum Exhibitions. *Association for Computing Machinery*.
14. S. M. Hasan, "Augmented reality and digital twin system for interaction with construction machinery," Journal of Asian Architecture and Building Engineering. [Online]. Available: https://www.tandfonline.com/action/showCitFormats?doi=10.1080%2F13467581.2020.1869557. [Accessed: 21-Mar-2023].
15. L. Yvkoff, "Hyundai builds a better car manual using augmented reality," *Forbes*, 09-Dec-2015. [Online]. Available: https://www.forbes.com/sites/lianeyvkoff/2015/12/09/hyundai-builds-a-better-car-manual-using-augmented-reality/?sh=34b68c815ec1. [Accessed: 21-Mar-2023].
16. L. Cuthbert. "Antikythera Mechanism" CAD files. 2019. https://grabcad.com/library/antikythera-mechanism-4

17. A. Tsigkros, B. Feidler, and P. Gurevich, “Mathematical aspects of the Antikythera Mechanism,” thesis, 2015. http://dynamics.mi.fu-berlin.de/preprints/TsigkrosBachelorarbeit%202015-02-04.pdf