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Replicating the Kinora: 3D modelling and printing as heuristics in digital media history

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Kinora, motion picture technology, early 20th century, home cinema, 3D modelling, desktop manufacturing, rapid prototyping, interdisciplinarity, experimental media archaeology, digital media history.

This article reflects on the Kinora replica project, an interdisciplinary collaboration between the Luxembourg Centre for Contemporary and Digital History (C^2DH) and the Department of Engineering (DoE) of the University of Luxembourg. Combining historical inquiry with a hands-on and technical approach – involving the latest 3D modelling and desktop manufacturing engineering techniques – it provides insights into the process of making a working replica of the Kinora motion picture technology from the early 1900s.

2 **Kinora Replica 3D Model**
https://zenodo.org/record/6417747

4 Introduction

5 Kinora replica project

6 In recent years, there has been an increased societal and academic interest in the use of 3D modelling and printing techniques (*Papadopoulos 2020*, *Arrighi 2020*, *Wilson, Stott, Warnett, Attridge, Smith, Williams 2018*, *Lipson, Moon, Hai, Paventi 2004*). Within the interdisciplinary fields of digital humanities and digital history, often in relation to the domain of cultural heritage, 3D replication techniques have been appropriated as heuristic methods for analyzing, interpreting and presenting historical artefacts in new and engaging ways (*Coughenour, Vincent, Kramer, Senecal, Fritsch, Gutirrez, Bendicho, Ioannides 2015*, *Papadopoulos, Earl 2014*, *Harkema, Rosendaal 2020*, *van den Oever, Rosendaal, Warnders 2016*). This article highlights the fruits of such an interdisciplinary collaboration, in which we – a media historian and an engineer – joined forces in a hands-on digital media history project to make a 3D replication of a special object in the history of cinema: the Kinora (1896-1914). This motion picture technology from the early 1900s was one of the first motion picture technologies designed for home use. The Kinora viewer functioned as an individual viewing machine that made use of a flipbook mechanism, in which a series of paper-based photographic cards were attached to a wheel. By turning the wheel and looking through the viewer, one could watch a series of photographs in motion. Our historical inquiry of this almost forgotten yet important media historical object combined a hands-on and technical approach, involving the latest 3D modelling and desktop manufacturing engineering techniques. The aim of the project was to use 3D replication as a heuristic method to better understand how the Kinora worked and was used in the past as a historical motion picture mechanism.

7 This article reflects on the Kinora replica project from both a methodological and epistemological perspective. As such, it aims to address two central questions. Methodologically, it addresses the question how the 3D replication of a historical object can serve as a heuristic method for doing digital media history. Specifically, in the case of our project, how to make use of 3D modelling and desktop manufacturing engineering techniques to investigate the materiality, functionality and (historical) usages of the Kinora? The question of what new insights this brought us methodologically is closely related to the epistemological perspective the article addresses, namely: what new forms of knowledge does the combination of hands-on historical inquiry and the state-of-the-art technical approaches from mechanical engineering produce?

8 The Kinora replica project was conducted within the framework of the research project "Doing Experimental Media Archaeology" (DEMA), which explores the heuristic potential of hands-on experimentation for media historical investigation. As a methodological approach, experimental media archaeology departs from the idea that hands-on experimentation with media historical technologies facilitates a more object-oriented and sensorial approach to media historiography. It argues that experiencing the materiality and workings of past media technologies, rather than only reading about them in the historical sources, contributes to a better historical understanding (and imagination) of their practices of use (*Fickers, van den Oever 2019*, *Fickers, van den Oever 2019*, *Fickers, van den Oever 2014*, *Fickers, van den Oever forthcoming*, *Fickers 2015*, *Fickers 2018*, *van den Oever 2015*). For the DEMA project, we had the opportunity to purchase an original Kinora viewer from circa 1907, including five reels, so it could be used for hands-on research and experimentation. As such, it served as a model for our replication process. We should emphasize up front that the goal of the Kinora replica project was not necessarily to create an exact or authentic replica, but instead to make a *working* prototype. The replication process itself served as a heuristic practice for understanding some of the original distinguishing features of the Kinora, which subsequently could lead to a better understanding of how this historical motion picture technology was made and used in the past. Doing so, we assumed at the beginning of the project, would not only bring us closer to the "historical user", but also to those inventors and "tinkerers" of the Kinora as one of the first home cinema technologies ever made.

9 Overview

10 In reflecting on the process of replicating the Kinora, this article aims to demonstrate three things. First of all, we aim to demonstrate the heuristic potential of 3D modelling and application of desktop manufacturing engineering techniques in doing digital media history, in our case the investigation of a specific media historical technology and its practices of use. Secondly, we aim to demonstrate the methodological and epistemological opportunities and challenges of our interdisciplinary collaboration, combining hands-on historical inquiry with mechanical engineering techniques for the production of new knowledge about the histories of use and production of past media technologies. Finally, by embedding or linking to various engineering drawings, pictures and videos documenting our replication process, the article aims to demonstrate the potential of digital documentation tools for both the capturing and dissemination of hands-on research experiments and 3D replication processes.

11 The article is structured in seven parts. After introducing the Kinora replica project, the second part discusses the historical context of the Kinora as an early 20th century motion picture technology and its historical usages. This part also highlights some distinctive features of the Kinora mechanism's kinematics, on which we focused in the replication process. The third part addresses the theoretical and methodological approaches of the replica project, combining experimental media archaeology as a hands-on experimental approach with 3D modelling and desktop manufacturing engineering techniques in the Engineering 3D Lab. The fourth part discusses the process of making the replica, its challenges and phases of development. In the fifth part we discuss how the Kinora replica was used for testing certain parameters, including the optimal distance between the two lenses in the lens hood and their degree of magnification. These tests helped us to identify several essential features of the Kinora system. In the sixth part, we reflect on the opportunities and challenges the replica project brought us. How have the hands-on approach and "opening up" of the Kinora through 3D modelling and printing enabled a better understanding of the object's materiality, functionality and usage? What were the

main challenges of the replication process, and what have we learned from this from both a media historical and engineering perspective? In the conclusion, we summarize our findings and provide ideas for future research and improvement of the Kinora replica model.

12 Historical context

13 About the Kinora as a historical object

14 Within this section, we would like to present a brief history of the Kinora and the historical context in which it emerged as a motion picture technology. While the Kinora is an almost-forgotten technology nowadays, it used to be a relatively popular system for home entertainment in the early 20th century. According to film historian Barry Anthony, who reconstructed the history of the Kinora system in his book *The Kinora: Motion Pictures for the Home, 1896-1914*, it was even considered “the most successful of the ‘home movie’ machines marketed in Britain before 1912” (*Anthony 1996*, 3). The Kinora system was originally invented and patented by Auguste and Louis Lumière in 1896, a year after the release of their Cinématographe: one of the first cinematographic apparatuses that enabled the projection of moving images on a screen. Unlike the Cinématographe, the Kinora was an adapted version of the Mutoscope, which similar to Edison’s Kinetoscope functioned rather as an individual viewing machine.

15 Kinora reel, viewer and camera

16 The Kinora system contains three parts: a viewer, a reel and a camera. A typical Kinora reel contains a brass core, which holds 640 curved photographic images printed on bromide paper with an image size of 24 mm x 19 mm each. The brass core of the Kinora reel includes a small hole, used to mount the reel to the Kinora viewer. The round shape of the Kinora reel and the curved form of the image cards are distinctive characteristics of the Kinora system. Hundreds of Kinora reels and various Kinora viewers were manufactured in France (by the film production company Gaumont) and, particularly, in England (by the film production and exhibition company British Mutoscope and Biograph Company, and later by the Kinora Company and Bond's Limited in London) (*Anthony 1996*, 6, 14). Most Kinora reels were printed reproductions of professionally shot films, which people could buy or rent for home viewing purposes. As such, the Kinora can be seen as the precursor of the home cinema of the film era, the video rental store of the 1980s and 1990s, and contemporary digital streaming media platforms, like Netflix (*Anthony 1996*, 18, *National Film and Sound Archive of Australia (NFSA) 2019*).

17 There were various models of Kinora viewers, varying from basic wooden hand-driven versions to luxury clockwork-driven models with multiple windows mounted on cast pedestals. The Kinora viewer that we used for the replication is a basic model which contains a wooden plate, a lens hood in the shape of a stereoscope viewer and two magnifying lenses inside this lens hood. Furthermore, it features a mechanism on which the Kinora reel can be mounted and manually turned by means of a rotating handle. By rotating the handle, the reel is activated and each of the 640 image cards are successively displayed in front of the lens. Depending on the speed of rotation, a reel contains about 40 seconds of pictures in motion. A small metal stop that is positioned at the edge of the viewer's guidance briefly arrests and disassociates each of the curved image cards during rotation and thereby flattens them at the very moment they become visible through the lens. This

then creates the anticipated illusion of movement when watching the series of images through the viewer. In *Moving Pictures* (1914), Frederick A. Talbot describes the process as follows:

18 > There is a small handle at one side whereby the reel of pictures is rotated through simple gearing, while a metal finger rests lightly upon the extreme outer edge of the leaves in such a way as to permit only one picture to turn over at a time. When this handle is turned and one is looking through the magnifying glass, the leaves fly over in rapid sequence, producing a vivid illusion of animation. (*Talbot 1914*)

19 While the images of most of the early Kinora reels were based on reduction prints of 35 mm films, a special Kinora camera was introduced around 1908, after several years of development by the Biograph company (*Anthony 1996*, 11–13, *Brown, Anthony 1999*, 171). This camera was mainly targeted to (upper) middle-class families and amateurs, allowing them to make their own Kinora home movie recordings. The Kinora camera made use of unperforated celluloid film or light sensitive paper with a width of one inch (25.4 mm) (*Coe 1981*, 163).

21 Kinora historical usages

22 The Kinora motion picture system generally served three types of use: home cinema, motion picture portraiture, and home moviemaking. Initially, home cinema was the first type of use of the Kinora, as Barry Anthony writes, namely: “to buy (or rent) popular reels of subjects primarily intended for theatrical presentation as films” (*Anthony 1996*, 3). Kinora reels featured a wide variety of subjects and genres, including child portraits, moving trains, comedic sketches, sports events, nature, newsreels, trick films and public parades. The fascination with capturing movement is a shared characteristic of most of the Kinora reels imagery, similar to early cinema titles in general. While the first Kinora reels featured short film prints that were professionally produced, a few years later – in 1903 – it became possible to have one's own "animated portraits" taken and transferred to a Kinora reel at the company's photographic studio in London. Motion picture portraits – described in the advertisements as “animated family portraits” or “living portrait albums” – were recorded and transferred into Kinora reels at the Biograph Studio (107 Regent Street), and later by Bond’s Limited, both based in London (*Anthony 1996*, 9, 11).

23 > Private Portraiture – Important. Your own Animated Portrait! Or that of your Family and Friends! Arrangements can now be made for photographic sittings of individuals or groups for Kinora Picture Reels. Thereby the Kinora becomes a living portrait album – reproducing in movement and with startling semblance to life the features and forms of dear ones. Parents, Husband, Wife, Children, Friends, Pets, LIVE FOR EVER IN THE KINORA. (*Anthony 1996*, 11)

24 A third type of use emerged around the year 1908, when the Kinora motion picture camera appeared on the British consumer market and was promoted as an instrument for families to take their own home movies. The introduction of the camera for home moviemaking can be explained by a change in the film landscape, in which longer narrative feature films were favoured over short running titles. As a consequence, the home cinema type of use of the Kinora couldn't cope with these transformations as there was, as Barry Anthony explains, “little potential for the Kinora to extend its running time, to make it more suitable for narrative productions, and viewing a professional Kinora subject at home no longer equated with the experience of attending a public filmshow” (*Anthony 1996*, 12–13; double-length Kinora reels with 1280 pictures for use in adapted viewers were released yet these were not very popular, see *Anthony 1996*, 19). This explains, at least partly, why the Kinora Company

introduced the consumer camera and promoted the practice of making your own Kinora reel as one of the motion picture system's new forms of attraction. In a large British advertising campaign of 1911-1912, when Bond's Limited took over the Kinora system from the British Mutoscope and Biograph Company, the Kinora camera was described as "the camera that has revolutionised photography":

25

> Without knowledge of Photography, without Chemicals, without fuss or focussing, the all-British Kinora Motion Camera makes the most enchanting child-portraits (in motion), pictures of outdoors, sporting and social scenes, studies of golfing strokes for practical use, and every other kind of Living Pictures at a trifling cost. (*Anthony 1996*, 15)

26 The advertisements furthermore emphasized the simplicity and ease of use of the Kinora viewing system: "A reel can be put into the instrument in three seconds" (*Anthony 1996*, 17) and, unlike the highly flammable nitrate celluloid film, was safe to use at home (*Herbert 1991*, 106). The Kinora, as another advertisement stated, made the "dark room, the magic lantern, the dangerous film [...] all vanish" (*N.N. 1911*).

28 Animated photography

29 Advertisements of the Kinora system, fully named "The Kinora System of Animated Photography", used to describe the motion picture technology in terms of "the newest photography" or "the latest and greatest achievement in animated photography" (*Anthony 1996*, 14, *Brown, Anthony 1999*, 171, 176; see for examples of animated lenticular photography: *Timby 2015*). Similar to the chronophotography experiments conducted by Muybridge, Marey, Friese-Greene and other film pioneers in the late 19th century, the Kinora is based on the physiological principle of "persistence of vision" to generate the illusion of movement. Although the Kinora was invented in 1896, therefore after the invention of the cinema as a medium for the projection of moving images, it is sometimes described as a "pre-cinema" device (*Herbert 1991*, 104). In the book *Living Pictures: Their History, Photoproduction and Practical Working*, Henry V. Hopwood presents the Kinora together with various pre-cinema technologies, like the Phenakistoscope (1833), Zoetrope (1860), among various other pre- and early cinema technologies in which the "illusion of motion [is] produced by successive views of slightly varying diagrams" (*Hopwood 1899*). In particular the Mutoscope (1894), also known as the "What the Butler Saw" machine, serves as a main reference. The Kinora, according to Hopwood, "is very similar in principle" (*Hopwood 1899*, 39). Media historian Stephen Herbert likewise describes the Kinora as "a miniaturised mutoscope", but also importantly refers to the stereoscope as domestic medium and "[p]erhaps the viewing device most closely comparable to the Kinora" (*Herbert 1991*, 105). As Talbot explains, the Kinora "recalls the stereoscope in design, only instead of two lenses it has one large rectangular magnifying-glass" (*Talbot 1914*, 304).

30 Herbert furthermore connects the Kinora system to other late 19th and early 20th century motion picture technologies that enabled "animated portrait photography", like the Filoscope (1897) and Biofix (1911) (*Herbert 1989*). These animated portraiture devices were similar to the Kinora based on the flip book motion picture principle. They emerged after the development of cinematography, which enabled the use of "frames from photographically-produced motion pictures as source material" (*Herbert 1989*, 65). The Filoscope, among others, used cinematographic frames from the British film pioneer Robert Paul's early films for printing the images on the paper leaves (*Barnes 1997*, 107-108). In a similar way, the Kinora reels from the Kinora library are based on frames of early films produced by the Mutoscope and Biograph Company (*Brown, Anthony 1999*, 170). While the

Kinora system was thus literally based on the new printing possibilities brought by cinema as a medium, its technological mechanism and materiality still predominantly drew upon the individual viewing experience of the flipbook and other pre-cinema motion picture technologies. In terms of its design and domestic context of use, the Kinora viewer can furthermore be seen as an extension of earlier photographic and stereoscopic devices. The Kinora, originally designed as an individual motion picture viewing machine, was so arguably positioned "in between" pre- and early cinema motion picture technologies as well as film and photography as visual media within its historical context of emergence (*van der Heijden 2022*).

31 Reading the Kinora patents

32 Studying the original Kinora patents was helpful for our replication process, as they highlight the distinguishing features of the Kinora as a technological system. This was helpful for understanding the kinematics of the system – as we will show in the next section. Let's first zoom in on the patent's description of some of the distinguishing technological features of the Kinora system, including the image curvature and stop, lenses and magnification, and the viewer's worm gear mechanism.

33 Image curvature and stop

34 Two distinguishing features of the Kinora system include the already mentioned curvature of the photographic image cards of the Kinora reel and the small metal stop attached to the Kinora viewer. Their function is to briefly arrest, disassociate and flatten the 640 image cards successively upon rotation. In *Living Pictures* (1899), Henry V. Hopwood writes about this principle, in reference to the original Lumière Kinora patent:

35

> A stop (C) arrests the pictures before they reach the lens, to the axis of which they are held at right angles, the curve in the flexible support straightening out to compensate for the rotary movement of the axle. Each picture therefore lies perfectly flat for inspection and then flies rapidly past the lens, returning to its proper radial position and curved form by virtue of its elasticity. (*Hopwood 1899*, 39)

36 The reason for the curved shape of the photographic image cards is explained in the original Lumière Kinora patent as follows:

37

> The wheel might be formed of flat cards radiating from the centre of the shaft (A) but in such case the stop (C) would curve the pictures at the moment of vision; this is why it is preferred to curve the cards previously in order that they may be presented flat during observation. (*Anthony 1996*, 4)

39 A 1912 patent of the Kinora viewer, entitled "Improvements in Cinematograph Apparatus", describes the same mechanism, yet in slightly different terms:

40

> In order to separate and expose the pictures as the reel is rotated by means of the handle (n), worm shaft (e), and worm wheel (h), a lip (o), is adapted to engage the outer edges of the picture strips in succession and to temporarily hold the strips until under their own elasticity they can successively flick past the lip. (*Chipperfield, Garforth 1912*)

41 One noticeable detail is that in this 1912 patent the viewer is described as a “cinematographic apparatus”, whereas the Lumière patent describes it as an “apparatus for the direct viewing of chrono-photographic or zoetropic pictures” (*Lumière, Lumière, Mills 1896*). These references of the original Lumière Kinora patent to both chronophotography and the Zoetrope demonstrate the earlier mentioned intermedial relationships of the Kinora as motion picture technology. While the drawings of the patent show many functional and aesthetic similarities -- compare for instance the Lumière Kinora patent from 1896 with the Mutoscope patent from 1898 (*Koopman 1898*) –, a reference to the Mutoscope is not explicitly given. Instead, the Cinématographe is mentioned in the Lumière patent in relation to the images on the Kinora reel:

42

> The successive pictures of an animated scene, obtained by Lumière's Cinématographe or by analogous apparatus, are cemented on cards (M) or other elastic opaque supports, to which a curved form is given, the picture occupying the concave side. These cards are then mounted, in the order of succession of the pictures, on a shaft (A), around which they radiate in every direction, being firmly fixed at their base by the pressure of two discs (B B), or by other suitable arrangement. (*Lumière, Lumière, Mills 1896*)

43 A patent from 1912 describing the Kinora reel, entitled “Improvements in Rotary Moving Picture Apparatus”, describes how each of the 640 images or pictures (d) is part of a strip which is attached to a spool (a). The spool contains a circular core, referred to in the patent as central tube (g). This central tube contains different edges or flanges, namely: the main flanges (h) and their ends (i), and the binding flanges (f). The binding flanges (f) have dished parts (e), which correspond to the incuts made on each of the sides of the image strips. Neither the 1896 nor 1912 Kinora patent provides information about exactly *how* the photographic image cards were attached to the reel. The 1912 Kinora reel patent however states that “the spool (a) is composed of a large number of cinematograph pictures in strip form arranged radially in a well known manner, and fixed to a back (b) of canvas, or the like” (*Cheers, Smedley 1912*, see also *Talbot 1914*, 304). Based on this, we assume that in order to fix the cards to the spool, the cards are glued to a piece of canvas, which is subsequently glued to the spool’s core. It should be mentioned, however, that such a canvas was lacking in the case of some of the original Kinora reels we have studied.

45 Lenses and magnification

46 The various Kinora patents give some information about the lenses and their function to magnify the images on the reel during their rotation. In the original Kinora Lumière patent, whose design is rather different from the basic wooden Kinora viewer that we have used as a model for the 3D replication process, only one lens is mentioned as an optional part of the viewing mechanism: “The opening (E) can be provided with a lens (G) to magnify the pictures and with any other known arrangement for assisting observation” (*Lumière, Lumière, Mills 1896*). Whereas in our Kinora viewer model the two lenses are fixed in the metal lens hood, some other Kinora viewer models featured a more flexible design that allowed the lenses to be mutually adjusted. Such a flexible model is actually the subject of the Kinora viewer patent of 1912, which presents the use of lenses as a (preferable) option:

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> The pictures so separated and exposed are preferably viewed through lenses (2)(3) carried in holders (4)(5), provided with lugs drilled to receive the rod (k), in which they are secured in the desired positions, by set screws (6)(7). In some cases only one lens may be employed or both lenses may be omitted. […] The holders (4)(5) are open frames […] The lenses have bevelled edges and the corresponding faces

> (10), on the holders are bevelled or undercut, so that pieces of rubber (11), may be inserted to hold the lenses firmly in position. (*Chipperfield, Garforth 1912*)

48 While the Kinora viewer originally only allowed for individual viewing, another type of Kinora viewer was patented in 1901 (and introduced to the British market in the next year), which featured multiple windows as "sight holes" on the Kinora images - after an idea developed by Elias B. Koopman, managing director of the British Mutoscope and Biograph Company (*Anthony 1996*, 6). In the patent of this specific Kinora viewer, a more elaborate description is included of the role of the lenses and their magnification in the Kinora viewing experience:

49

> I prefer to fit each sight aperture with a suitable lens magnifying the picture, so that a person standing a little distance from the apparatus may still be able readily to view the pictures as they pass. [...] I may also place one lens in front of the picture, (between it and the sight holes) so that each sight hole is on one of the radii of such lens. In some cases I place one lens close to the picture and a series of lenses in the sight holes, the latter arranged along the radii of the first. With the last mentioned arrangement the picture as seen is twice magnified. (*Koopman 1901*)

51 In the case of our basic wooden Kinora viewer model, however, the use or positioning of the lenses is not optional. The lens hood includes two lenses, one in the middle and one at the bottom.

52 **Worm gear mechanism**

53 The worm gear, referred to as the "worm wheel" in the Kinora patents, plays a central role in the general mechanism of the viewer. During rotation, it connects the reel to the worm shaft that is activated by the rotating handle. The worm gear furthermore defines the speed ratio, as we will explain in the next section. The Lumière Kinora patent mentions a speed of one revolution per scene: "As the wheel makes only one revolution or part of a revolution during the viewing of a scene, it moves at a very moderate speed; it can be put in motion by hand by intermediate gearing, or better by a spring motor" (*Lumière, Lumière, Mills 1896*). As mentioned, unlike those more luxury spring-driven models, the worm gear of our basic Kinora viewer is manually driven.

54 Kinematics of the system

55 The worm gear mechanism is central to the kinematics of the Kinora as a motion picture technology. The original design proposes a worm with one tooth and a worm gear with 50 teeth. This mechanism leads to a gear ratio of 1/50:
Gear ratio = number of teeth worm / number of teeth worm gear = 1/50

56 In addition, the gear ratio defines the speed of the mechanism:
Gear ratio = outlet speed / inlet speed = worm gear speed / worm speed (equation 1)

57 An inlet rotation speed of the handle of one rotation per second results in an outlet speed of 0.02 rotation per second. A Kinora reel has 640 frames in total. However, those frames are not displayed along 360 degrees of the reel holder diameter. There is a gap between the frame to ease the location of the beginning and the end of the movie.

59 Therefore we can assume the frames are located along 315 degrees. During one second, the reel therefore rotates by:

360 x 0.02 = 7.2 degree

60 Per degree the number of frames is:
640/315 = 2.032 frames / degree

61 From those two last equations we can evaluate the number of frames per second:
Number of frames per second = 7.2 x 2.032 = 14.6 (equation 2)

62 These calculations suggest that the full 360 degree rotation of one Kinora reel takes 50 turns or revolutions with the rotating handle, corresponding to the number of teeth on the worm gear. In the case of an inlet speed of one revolution per second, 14.6 images are being successively displayed for the lens of the viewer. The total duration of watching one reel is 43.75 seconds in that case. When the speed of rotation increases to two revolutions per second, 2 x 14.6 = 29.2 images are being successively displayed for the lens. The total duration of watching one reel is 21.9 seconds in that case. Tests show this speed does not lead to realistic animation. (We will further discuss the optimal speed of rotation in the section *Optimal relation between the recorded frame rate and the viewer's speed of rotation*, see below.)

64 The worm gear mechanism is offering several interesting design particularities adapted to the Kinora viewer. These include the compact size of the mechanism, which is well proportioned to the reel. The mechanism furthermore provides a high speed reduction. This could not have been obtained when using traditional spur gears, for instance. Finally, the mechanism is relatively quiet and provides smooth rotation when well assembled and lubricated (for more insights into the importance of the worm gear as a technique within mechanical engineering in the early 20th century, see *Oberg 1920*).

65 Experimental Media Archaeology in the Engineering 3D Lab

66 In this third section, we would like to present the theoretical and methodological frameworks we drew upon and the 3D modelling and printing facilities of the Engineering 3D Lab that we used for replicating the Kinora.

67 Experimental Media Archaeology

68 The Kinora replica project was conducted within the framework of the research project “Doing Experimental Media Archaeology” (DEMA). One of the aims of the DEMA project is to reflect on the methodological underpinnings of experimental media archaeology as an object-oriented and sensorial approach to media historiography. Inspired by the concept of “thinkering”, developed by media archaeologist Erkki Huhtamo (*Huhtamo 2010*), it departs from the idea that a hands-on and experimental approach allows media historians to re-sensitize themselves to the materiality of historical media technologies and the tacit knowledge that is involved in their technical, social and cultural usages. Doing media archaeological experiments and historical re-enactments, Andreas Fickers and Annie van den Oever argue in their article “Experimental Media Archaeology: A Plea for New Directions”, “will produce new historical, ethnographic and empirical knowledge about past user practices and media experiences” (*Fickers, van den Oever 2014*, 276). As a methodological approach, experimental media archaeology thereby shifts from a discourse-oriented to a more practice-based approach to media historiography. Complementary to the study of past

media technologies and their histories of use on the basis of written historical sources, it aims to bring forward a new perspective which helps to make explicit some of the tacit, experiential and sensorial dimensions of past media usages (*Fickers, van den Oever 2019*, 50).

69 By turning the media historian into an experimenter, experimental media archaeology stimulates scholars to open up media historical objects as technological "black boxes" and to transform museums and archives into research laboratories (*Fickers, van den Oever 2014*, *Fossati, van den Oever 2016*). Inspired by experimental research done in the domains of experimental history of science (*Breidbach, Heering, Müller, Weber 2010*, *Hendriksen 2020*), experimental archaeology (*Ferguson 2010*), historically informed music performances (*Kolkowski, Miller, Blier-Carruthers 2015*), sensory ethnography (*Pink 2009*, *Kneebone, Woods 2014*), sensory education (*Harris 2021*) and performative methods in the humanities and social sciences in general (*Dupré, Harris, Kursell, Lulof, Stols-Witlox 2020*), Fickers and Van den Oever argue that one of the values of the hands-on approach for both the contexts of research and education is that it triggers the historical imagination and so allows for new ways of "sensing the past" (*Fickers, van den Oever 2019*, 49). Historical re-enactments and media archaeological experiments furthermore enable researchers to capture the embodied and tacit knowledge that is involved in the usages of media historical objects (*Hall, Ellis 2019*). The DEMA project aimed to systematically explore this heuristic potential of experimental media archaeology and their methodological and epistemological implications (*van der Heijden, Kolkowski forthcoming*).

70 One of the practical and methodological challenges includes the question of how to document the hands-on experiments, sensorial experiences and new knowledge they produce? To contribute to this question, we have extensively documented our process of making the Kinora replica. Thereby, we made use of traditional approaches for documentation, such as the writing of lab diaries and reports, but also utilized various digital documentation tools, including a regular photo and video camera, a live action video camera (GoPro), and a 360 degree video camera (Insta360). This combination of written reflections and audio-visual documentation proved to be a valuable method for both capturing and analysing the replication process and its various phases of development (*Fung 2016*, *McCaslin, Young, Kesireddy 2014*). The majority of this documentation footage has been recorded in the Engineering 3D Lab. The lab not only provided us the facilities for the generation of 3D numerical models and desktop manufacturing by means of state-of-the-art 3D printing technologies and laser cutting, but also gave us the opportunity to test, demonstrate and experiment with the various Kinora replica prototypes and to perform and document the different user tests ourselves. As such, it served as a "laboratory space" for both conducting and documenting our hands-on experiments and replication processes (*Latour, Woolgar 1979*, *Wersher, Emerson, Parikka 2021*).

71 3D modelling and desktop manufacturing in the Engineering 3D Lab

72 The Engineering 3D Lab - officially called "3D Rapid Prototyping Laboratory" - of the Department of Engineering (DoE) at the University of Luxembourg is used for education and research activities. All different steps of virtual product development and rapid prototyping are used and taught through research projects, engineering product development, project based learning and conventional lectures. The generation of the 3D models is done using cutting edge software in the field of Computer Aided Design (CAD). Feature based models, parametric models, and associative assembly are used for the development and generation of numerical models. Having such flexibility in the models during the replication enables easy interaction on the assembly tolerances, parts location and geometry modification,

according to the manufacturing technologies that will be used later on. The numerical models can be validated and assessed in terms of strength, displacement and function using finite element analysis or computational fluid dynamics, when or if relevant. This optimisation of the numerical model allows us to verify the part before producing it.

73 Various desktop manufacturing technologies are represented in the Engineering 3D Lab. For each technology we have developed expertise with different methods. For additive manufacturing the Kinora viewer replica, various FFF (Fused Filament Fabrication) printers, SLA (Stereolithography) printers, SLS (Selective Laser sintering) printers and laser cutting were used. For the printing of the different parts of the Kinora viewer and reel replicas, we used various FFF 3D printers (ULTIMAKER2, ULTIMAKER3, ULTIMAKER5, PRUSA and Onyx Markforged). The Onyx Markforged can print in Nylon polymer.

75 For replicating the Kinora we used rapid prototyping, including 3D modelling, as methods in mechanical engineering. For designing the 3D models, we followed Dieter and Schmidt's five steps of engineering design methods: state of the art, identification of need, conceptualization, feasibility analysis, and production (*Dieter, Schmidt 2009*, 9). After taking some pictures and measurements of the physical parts of the original Kinora viewer and reels, we created a numerical solid model of the mechanism. Computer Aided Design (CAD) software allows the generation of solid models of every single part. For each part the main parameters subject to change can be identified and set as variables. Later on in the design process those variables can be fine-tuned to improve and optimise the design in an easy way. The different pictures taken upfront can be imported and scaled in the software to reproduce similar parts at low measurement costs. Once all parts are modelled, they can be numerically assembled. This assembly allows validation of the mechanism in addition to verification of no interference between the parts and functionality of the mechanism. The geometry of the parts is set according to the manufacturing method considered.

76 Designing CAD models has various advantages:

- Features modelling method: the numerical models are built using features which can be accessed any time. The design can therefore be modified as needed.
- Adaptive geometry: the different parts can be modelled in such a way that they are interacting and adaptive to each other. A modification of one part can lead to the modification of surrounding parts.
- Parametric modelling: the use of parameters within the feature leads to great potential of modification at low cost.
- Documentation: the engineering drawings, explosion, bill of material and animation can easily be documented as all the files are connected to each other. A modification on the geometry results in modification of the drawing, as well as the geometry for manufacturing.

77 After making the CAD models, the third step is to validate the mechanism using simulation capabilities, such as Finite Element Analysis (FEA) or computational fluid dynamics depending on the product function. An FEA will determine the structural stiffness of the part or mechanism, and validate the geometry of the parts to withstand the external loads applied on it. Depending on the results the geometry of the part is optimised to fulfil all stress requirements and validate the function prior to manufacturing. The numerical model is optimised prior to fabrication.

78 The fourth step is to export the part geometry for manufacturing. The prototype will then be physically created using various desktop manufacturing technologies. Desktop manufacturing methods are using the numerical model to drive the machine that will produce the parts. Additive manufacturing (also called 3D printing), subtractive manufacturing (traditionally milling and lathe machines) and laser cutting are the most common known. The geometry of the numerical model is used to define the path of the machine and produce the part. This full procedure is called rapid prototyping. It allows the generation of functional and optimised prototypes in a reduced time, in addition to the great potential of "what if scenarios". Once the first prototype is created it can be quickly tested and optimised if needed (for information about 3D printing and CAD modelling, see further: *Chua, Leong 2017*, *Madsen, Madsen 2017*, *Chang 2014*, *Gibson, Rosen, Stucker 2009*).

79 Making the Kinora replica

80 This section zooms in on the actual process of replicating the Kinora. From the start we kept the idea to have an open source design that could easily be reproduced with limited desktop machines, therefore at low cost. Throughout the replication process several design iterations were needed to reach an optimum and functional design. To replicate the Kinora viewer, we made three different prototypes in total. The first two prototypes laid the groundwork for the third prototype, which worked successfully. We will now describe the processes of replicating the viewer and reel prototypes, involving the steps of taking the measurements of the original objects and the generation of the 3D models, including potential optimization and future design modification, production of the prototypes, tests and design optimization for function improvement.

81 Replicating the viewer

82 We started by taking full measurements of the original Kinora viewer as an object. Thereby, we focused on some of the crucial elements and dimensions that were needed for testing our parameters, for instance the dimensions of the lens hood and distance between the low lens at the bottom of the viewer and the position of the flattened image of the Kinora reel. See the figure below for an example of the measurements that were taken.

84 For the 3D modelling process, we identified five main elements that play a crucial role in the functioning of the Kinora viewer: (1) the viewer's lens hood, including its two magnifying lenses; (2) the wooden support plates, on which the lens hood rests; (3) the worm gear and worm shaft, which enable the rotation of the reel; (4) the tilting arm mechanism that holds the reel in position and provides guidance to the Kinora images; and (5) the small metal stop that arrests, disassociates and flattens the motion pictures during the rotation of the reel.

85 Lens hood and magnifying lenses

86 The shape of the lens hood of the original Kinora viewer is reminiscent of a stereoscope. Instead of having two lenses next to each other (one eye for each), however, the lens hood of a Kinora viewer features two lenses on top of each other. The first lens ("high lens") is located in the middle of the lens hood; the second lens ("low lens") is located at the bottom of the lens hood. The function of these lenses in the lens hood is to magnify the Kinora image for presentation in the viewer. For replicating the lens hood and the two magnifying lenses, we used six prefabricated magnifiers with standard dimensions (50 mm x 100 mm) as a cost-efficient solution. The alternative would be to produce the lenses ourselves, for instance through moulding or manufacturing the glass. However, this would make the whole

process much more complex, expensive and time consuming. Moreover, it would require outsourcing some of the processes to an external partner, which might delay our replication project (especially in times of the COVID-19 pandemic). Selecting the low cost prefabricated lenses had no consequences for the functionality of the lens hood replica. They worked very well in terms of focusing and enlarging the Kinora images. After our first tests, we ordered more magnifiers with different magnification degrees - varying from 2x, 3x, 5x, 6x and 10x magnification, according to their descriptions - so we could use them in our comparative tests for finding the optimal magnification and configuration of the two lenses in the lens hood (parameter 2).

87 One of the consequences of this decision to use prefabricated magnifiers - also in terms of historical authenticity - was that we had to adapt the size of the lens hood to the dimensions of these magnifiers, instead of the original lenses of the Kinora viewer. This meant we had to slightly increase the size of the lens hood of the replica, so the magnifiers would fit. On the other hand, this option allowed us to keep our design open and accessible to anyone. The lens hood was designed in such a way that the lenses could be attached simply by placing them inside. After defining the optimal configuration, the lenses could be glued onto the plastic holders so they are fixed in the lens hood. However, this is not necessary, as the lens is set in a groove to ensure its location.

89 **Wooden support plates**

90 In total, there are three wooden plates that give support to the different parts of the Kinora viewer. The lens hood is attached to the “main plate”. The other plates are the “base plate”, which is the base of the apparatus, and the “support plate”, whose function is to support the standing main plate when the viewer is in use. For the replication of the three support plates we made use of MDF wood as material to stay close to the original model. In our 3D design, however, we slightly adapted the angle of the support plate from the 45 degrees of the original viewer to 60 degrees on the replica. This design choice would make the laser cutting process more convenient, because when laser cutting the wooden plates, the tongue and groove system connecting the main plate to the support plate has to be at 90 degrees.

91 To increase the stability of the replica, we furthermore decided to make the support plate wider on the back and let it slide all the way to the end (instead of half way, as in the original). Similar to the replication of the lens hood, one consequence of this design choice was that it made the part less authentic compared to the original. However, lifting the system to a 60 degree angle worked much better for the manufacturing process, as explained. Without completely changing its supporting functionality, it additionally improved the usage comfort in two ways. Firstly, the user no longer needed to hold the support plate with the left hand anymore, and secondly the user did not need to strain his neck to look into the hood.

93 **Worm gear and worm shaft**

94 Two other crucial elements of the Kinora viewer are the worm gear and worm shaft. The function of the gear is to rotate the Kinora reel. The worm shaft connects the worm gear to the rotating handle. There are fifty teeth on the original gear, which correspond to the full 360 degree revolution of one reel. This ratio was calculated prior to the design in order to keep a similar rotational speed and therefore reproduce an identical visual effect. The worm gear of the first prototype of the replica viewer was designed and 3D printed much larger than the original due to a difference in manufacturing technology. Since the FFF 3D printer of the Engineering 3D Lab that we used cannot print materials that are smaller than 0.4 mm,

we had to design a larger worm gear to keep the same functionality. In our first prototype we furthermore added an extra bearing on the extremity of the worm shaft to avoid it bending during rotation. We estimated that this would compensate for the differences in material qualities compared to the worm shaft of the original viewer, which is made from steel.

96 Nevertheless, the rotation of a reel in the first and second prototypes of the replica viewer resulted in a lot of friction and forces. This caused the worm shaft to bend and disconnect from the worm gear, leading to a failure of function. These forces could eventually lead to a broken worm shaft and/or pin of the worm gear. Solving this friction and bending problem was crucial for the overall functioning of the replica, so we tried multiple solutions and redesigned various parts. Amongst others, we increased the sizes of the guidance and axis, to make sure the images rotate without any obstruction, added another bearing for extra stability and support to the worm shaft in order to limit the bending at the extremity, and added various extra screws and spacers to the plate for additional support of the mechanism. However, even after implementing all of these changes there was still too much friction and resistance during rotation in the second prototype of the replica viewer. Rotating the reel made the whole system bend. In particular the worm gear was visibly affected by this, as the figure below illustrates.

98 To further enhance the support, we eventually decided to 3D print the worm gear and worm shaft of the replica viewer with a different type of material: Onyx nylon. Unlike regular nylon, this type of material is reinforced with carbon fibre in order to give it a strength comparable to aluminium. The nylon material replaced the PLA plastic material that was used in the first prototypes. In addition to the new type of 3D-printed material, we made several adjustments to the design of the worm shaft and worm gear (e.g. increased the thickness of the gear for better support), implemented a few extra bearings for additional support to the worm shaft, and attached these directly to the wooden main plate (instead of to the plastic assembly) to make the whole assembly more interconnected. Furthermore, the large pin of the assembly was made from metal and also made longer and thicker to increase the stability of the whole system during rotation. Other changes involved the increase of the distance of the axis between the left edge of the assembly and the core of the reel (from 72 mm to 75 mm) as well as the addition of blended fields to the edge of the guidance to give better support. The nylon material, in combination with these design modifications, eventually solved the friction in the worm gear and worm shaft. The mechanism functioned without any problems in the tests with the third prototype of the replica viewer. Nonetheless, as is common with 3D printing, some polishing, sanding and greasing had to be done to make sure the replicated worm shaft and worm gear enabled a smooth rotation.

99 Tilting arm mechanism and guidance

100 Closely related to the worm gear is the tilting arm mechanism. By means of this mechanism of the viewer, the Kinora reel is kept in place during the rotation. In the 3D design, we used a cylinder for replicating this function. Besides keeping the reel in position, the flexible arm furthermore serves as a guidance for the images on the Kinora reel. In our first prototype of the arm mechanism, the design did not account for this functionality, which made some of the images disconnect from the reel or even block the rotation. In the design of the second prototype, the flexible arm mechanism consequently became synonymous with the guidance that supports the images of the Kinora reel during the rotation. For better alignment, we furthermore added a spacer to the other side of the plate. This helped to center the image more within the frame.

102 **Stop**

103 The small metal stop is positioned on the edge of the guidance of the tilting arm. Its function – as we have seen in the original Kinora patents – is to briefly arrest, disassociate and flatten the curved cards on the Kinora reel. For recreating the stop, we used sheet metal instead of plastic in the 3D printing process to make sure it would function similar to the original. Furthermore, this gave us some flexibility for manually adjusting its position. With the first prototype, we encountered the problem that the stop was too visible within the frame of the viewer. We therefore decided to bend the stop slightly, as we were uncertain about how much to cut off. This should not be too much, we figured, otherwise the stop would not be able to arrest the images anymore. However, it should also not be too little, as this would then obstruct the view of the image and affect the overall perception and user experience. The user tests were helpful for determining the right balance.

104 After focusing on the functionality in the first prototype, we were able to implement several aesthetic changes as well. In the second prototype, for example, we painted the metal stop in black. This way, the stop became part of the window rather than a noticeable extra element. Consequently, it corresponded better to the original implementation of this feature.

106 Replicating the reel

107 To describe the process of replicating the Kinora reel, we need to distinguish between the reel itself and the image cards that it holds. We will start with the reel, and then focus on the image cards.

108 **Measurements**

109 Similar to the process of replicating the Kinora viewer, we started by taking measurements of the Kinora reels from our collection. See the figure below for a sample of the measurements that were taken.

111 During the measurement process, we found out that there are some differences and similarities between the "early" Kinora reel - produced by the British Mutoscope and Biograph Company between 1902 and 1911 - and the "late" Kinora reel - produced by the Kinora Company and Bond's Ltd between 1911 and 1914 (see for a list with characteristics of the various Kinora reels: *Anthony 1996*). The thickness of the image cards of both reels was similar. By means of a calliper, a measurement tool from the lab, we measured a thickness of approximately 0.16 mm. We furthermore compared the dimensions of the small and large holes of the two types of Kinora reels that correspond to the large and small pins of the viewer's worm gear. The incentive for taking these measurements was a problem we encountered during our tests with the first prototypes of the reel and viewer replicas. The problem was that we could not test an original Kinora reel on the replica viewer, because the values of the replica assembly were not matching those of the original reel. In other words, the original reel was not compatible with the replica viewer. By taking the measurements, we found out that this was the case due to some small variations between the diameters of the small and large ins on the viewer, the diameters of the small and large holes on the reel, and the distance between the two pins and holes.

112 The large and small pins on the original viewer have a diameter of 6.03 mm and 3.33 mm respectively. The large and small holes on the "late" Kinora reel have a diameter of 6.7 mm

and 4.04 mm respectively. The large and small holes on the “early” Kinora reel have a diameter of 6.5 mm and 3.9 mm respectively. The distance between the large and small pins (outer edge) on the original Kinora viewer is 13.65 mm. The distance between the large and small holes on the “late” Kinora reel is 14.21 mm, whereas for the “early” Kinora reel this is 15.5 mm - so more than 1 mm difference. The pin on the worm gear of the replica viewer (first prototype) had a diameter of 6.7 mm, so this explains why the original Kinora reel did not fit the replica viewer initially. The distance between the large and small pins on both the replica viewer and reel (first prototype) was 14.45 mm. This explains why unlike the “early” Kinora reel only the “late” Kinora reel with almost the same diameter (namely 14.21 mm) was able to fit the original viewer.

114 **Design**

115 The first prototype of the replica Kinora reel already worked to a large degree: it could be attached to both the original and replica viewers and the images were rotating. However, to make the replica viewer compatible with both the original and replica reels, we had to slightly modify the design of the replica viewer. In the design of the second prototype, we therefore changed some of the values. The large pin on the Kinora viewer (6.03 mm) fits both the diameter of the large holes on the “early” Kinora reel (6.5 mm) and “late” Kinora reel (6.7 mm). Similarly, the small pin on the Kinora viewer (3.3 mm) fits both the small holes on the “early” Kinora reel (3.9 mm) and “late” Kinora reel (4.04 mm). The original Kinora viewer allowed a difference of approximately 1 mm diameter between the large and small holes of the two original reels, so we tried to replicate this flexibility in our 3D model. We slightly changed the values, so it would be easier to implement. Instead of 13.65 mm, we used 14 mm as value for the distance between the two pins on the original viewer. The large pin on the viewer, we made 6 mm in diameter size. The small pin, we made 3.4 mm. To compensate for possible changes in values caused by the additive 3D printing process, we took a margin of 0.2 mm into consideration.

117 **Image cards**

118 For making the replica Kinora reel, we furthermore needed to replicate the 640 photographic image cards it holds. For this we used images from an analogue film recording that was part of another media archaeological experiment within the DEMA project. In this experiment, DEMA-researcher Tim van der Heijden made a home movie with an original 16 mm Ciné-Kodak film camera from the 1930s (see the C^2DH website for more information about Van der Heijden’s research within the DEMA project). We decided to use the first part of this black and white analogue film recording as image sequence for the replica reel. We converted the digitized film recordings of the 16 mm film into 640 successive frames. For producing the images, we used the same dimensions as an original Kinora image card, namely 24 mm x 19 mm. This gives an aspect ratio of 1:1.26, which slightly deviates from the standard 35 mm film aspect ratio of 4:3 or 1:1.33 that was used by W.K.L. Dickson, Thomas Edison and the Lumière brothers in the late 19th century (*Enticknap 2005*, *Belton 1990*). In the last prototype, we added a number on the left side of the image card, corresponding to the frame number on the reel. Although such numbering did not occur on the original Kinora images, it was used as a practice with the Filoscope and some of the late 19th century and early 20th century flip books (*Herbert 1989*, 66, *Berns, Gethmann 2005*).

120 **Image sequence**

121 For making the image sequence exports, we used several digital tools. In a video editing program we first set the right speed of the original 16 mm film fragment to render the export

of 640 successive frames. While the 16 mm film was originally recorded at a speed of 16 fps, it was scanned frame by frame at a speed of 25 fps, the default setting of the film scanner. Subsequently, we used a photo editing program for batch cropping and exporting the images into the right dimensions of 24 mm x 19 mm per frame. We chose PNG as export format, so the image sequence could be used within the design and 3D modelling program for further processing without significant compression. For the first prototype, we printed only 66 image cards to test in the first prototype of the replica viewer. These images were printed on 160 grams paper. Each of the image cards were manually cut; a rather time-consuming process. To automate this process, we tried to laser cut the next series of images on 80 grams paper with the laser scanner of the Engineering 3D Lab. This worked well, although there were some errors in the case of a few laser cut images. Outsourcing the process of cutting the images manually to the laser cutter machine eventually saved a lot of time.

122 One A3 sheet can include a maximum of 98 images. Thus per Kinora reel, seven A3 sheets were used for printing the total of 640 images on photo paper. The A3 papers were cut in the Engineering 3D Lab with the laser cutter machine. The challenge here was to define the origin of the cut and make sure the machine was aligned with the sheet.

124 Making a Kinora reel

125 After finishing the printing and laser-cutting processes, the 640 image cards can be connected to the Kinora reel. One of the challenges of producing the reel was the compression and attachment of the images. We accomplished this by means of gluing the images on a piece of canvas and subsequently glue the canvas to the core of the reel. The first step was to compress the images with a clamp. After this, the series of images were assembled in three parts. To make sure the image cards remained positioned and fixed to the core, we glued the three parts to the canvas. After putting double-sided adhesive tape on the core of the reel, we attached the canvas with the 640 images to the core.

128 Another challenge was the curvature of the images. In our user tests with the first prototype of the replica viewer, we experienced that when the images on the replica reel are not curved well enough, they partly block the view of the following images during the rotation. Being able to see the image completely, instead of just a part of it, is obviously a crucial element in the perception of moving images in general.

130 So, the question was: how to curve the images on the reel in such a way that the curvature remained, the reel would rotate smoothly and all images would be completely visible in the viewer during rotation? We first tried to curve the images on the replica reel manually. When comparing the flat images to the curved ones in the viewer, the noticeable differences in performance and perception made us more aware of the importance of the curvature as a distinguishing feature of the Kinora system. Eventually, we found a solution to curve the images on the replica reel by means of placing a rubber band around the images and keeping it in that position for several days. This helped to curve the images similar to the shape of the images on an original Kinora reel. Additional curving could be done manually, for instance by means of curving a stack of images around a pencil while holding the reel in place. This further enhances the visual effect in the viewer.

132 Kinora viewer replica and 3D model

135 Kinora replica 3D model in STL and STP.

137 Testing hypotheses and parameters

138 After making the working prototypes, we used the Kinora viewer and reel replicas in our user tests and hands-on experiments. We wanted to test the following four parameters: (1) the optimal distance between lens and image; (2) the optimal magnification of the lenses and distance between the high and low lens; (3) the optimal thickness of the image card, and to what extent this matters during rotation; (4) the optimal relation between the recorded frame rate and speed of rotation of the images in the viewer.

139 Optimal distance between lens and image

140 What is the optimal distance between the lens hood and image on the reel? Is it better to have the low lens, positioned at the bottom of the lens hood, closer to the image or further away? The possibility of the Kinora viewer replica's lens hood to modify the position of the lenses allowed us to experiment with different configurations in order to find this optimal distance between lens and image. In our tests we experimented with the optimal arrangement of the two lenses by means of comparing two Kinora viewer replicas side by side. In changing the position of the low lens vis-a-vis the image on the reel, we experienced how two factors influence the size and sharpness of the image. First of all, the image size and sharpness are determined by how far the lens is positioned from the image. In other words, the closer the distance between the image and the lens, the smaller the image appears within the viewer. Secondly, the size and sharpness of the image depend on the magnification degree of the used lenses. In order to find the optimal position, we tested the image appearance by combining lenses with different magnification degrees: varying from 2x, 3x, 5x, 6x and 10x magnification.

141 Our test results indicated, as expected, that the size of the image increases when we move the lens further away from the image on the reel. In terms of image sharpness, on the other hand, the impact was less significant. We found that the sharpness of the image is hardly affected when the lens changes its position from the bottom of the lens hood, so at the closest position to the image, to approximately half-way to the lens hood. Even when the low lens is all the way up the lens hood, so at its highest position, the image is still in focus. We therefore conclude that the image sharpness is less affected than the image size when changing the position of the lenses in the Kinora viewer. Nevertheless, both elements should be considered when determining the optimal distance between lens and image. The magnification degree of the lens plays an important role in this as well.

142 Optimal magnification of the lenses and distance between them

143 What is the optimal magnification of the two lenses and optimal distance between them in the Kinora viewer? This is the second question we asked and set as a parameter in our user tests. The six lenses with varying magnification degrees combined with the flexible lens hood of the Kinora viewer replica enabled the testing of this parameter, which is closely related to the previous one. What configuration would give the best results in terms of image sharpness and image size when looking through the replica viewer? Testing this optimal configuration could give additional insights into some of the design choices of the

original Kinora viewer, specifically concerning the design of the lens hood and position of the two lenses.

144 While testing the optimal magnification of the lenses and the distance between the high and low lens, we experienced that the effective differences between the lowest and highest magnification degree are not very noticeable. This is probably due to the relatively small space in the lens hood. Our tests showed that the optimal distance between the lenses is located somewhere in the middle: the place where the low lens is resting on the last pin and with a combination of lenses with 6x magnification (high lens) and 5x magnification (low lens). The optimal space between the high and low lenses within the lens hood is 4.8 cm. While the image would also still be in focus with a combination of two 2x magnifiers, it would not appear as large in size when looking through the viewer. We therefore concluded that changing the distance between the high and low lens does not make a great impact for the current configuration due to the limited space of the lens hood. However, when this space increases and moves *beyond* the limitations of the lens hood, the image becomes increasingly unsharp. Positioning the low lens closer to the image without moving the high lens makes the image appear both smaller and sharper.

145 Optimal thickness of the photographic paper card

146 What is the optimal thickness of an image card on the Kinora reel? To what extent does the thickness of the paper matter for the rotation of the replica viewer and the user experience? For testing this third parameter, we compared various thicknesses of paper for the replica reel. As we have seen in the previous section, there was no significant difference in thickness between the "early" Kinora reel that was produced by the British Mutoscope and Biograph Company and the "late" Kinora reel produced by the Kinora Company and Bond's Limited. The image cards on both reels have a thickness of approximately 0.16mm. But what if we increase the thickness, for instance by using 200 or even 250 grams of paper for the image cards?

147 For the first prototypes of the reel, we compared image cards made with 160 and 200 grams photo paper. We even tested a couple of 250 grams Kinora image cards, whose extra thickness caused some resistance during rotation. We concluded that there is indeed a correlation between the paper thickness and the functionality of the attached paper cards during rotation, but that this difference can be neglected in the case of image cards made of 200 grams paper or below. For the second series of reel replicas we used 120 grams extra glossy photo paper, mainly for aesthetic reasons. By exporting the images in high resolution and printing them on glossy photo paper, we hoped to improve the quality of the Kinora images. The difference in paper thickness seemed to have no effect in this case. Neither could we detect any noticeable difference in viewing experience in our user tests. The only noticeable difference was the fact that the 120 grams image cards were not only lighter but also thinner (0.13 mm). Therefore, more image cards could be used per reel to fill it: 685 versus 640 cards.

149 Optimal relation between the recorded frame rate and the viewer's speed of rotation

150 What is the optimal rotational speed? How does this relate to the frame rate in which the Kinora images have been recorded? This fourth and last parameter is a bit tricky, because the model of the Kinora viewer on which our replica is based is hand-driven and so

manually operated. The speed of rotation is thus variable and defined by the user (*Brown, Anthony 1999*, 170–71). Hence, there is no single "right" answer to the question of the Kinora frame rate and rotation speed in the viewer. As the British media historian Stephen Herbert writes, the frame rate could differ per use type. Studio portraits, he estimated, would most likely be taken with a conventional 35 mm cine camera at around 16 fps, whereas prints made from professional films – including both 35 mm and large-format Biograph films – were usually recorded with various speeds "from about 14 fps to maybe 20 fps or more", with most of the 35 mm and pre-1914 footage being "around 16 fps". In the case of amateur films made by the Kinora camera, the speed could vary as well, probably between 14-16 fps. This last speed range seems to correspond to a Kinora advertisement from 1908, which states that a Kinora reel "consist of 500 to 700 pictures, and are taken upon a film at the rate of 40 to 60 per second" (*Anthony 1996*, 36). The mentioned rate is most likely the result of a mistake, probably the mis-hearing of the dictation, and should actually be 14 to 16 pictures per second (*Herbert 2020*).

152 The recording speed of 16 frames per second was the "standard" frame rate for motion picture recording during the first decades of the 20th century (*Abel 2010*, 767). This frame rate corresponds to a rotation speed of two revolutions per second in the case of the Lumière Cinématographe, which "exposed eight frames per turn of the crank providing for 16 frames per second for two revolutions of the crank" (*The Malkames Collection *). The speed of two revolutions per second was also recommended in the early 1920s with the hand-cranked Pathé-Baby 9.5 mm film camera and projector, one of the first successful domestic film projection technologies (*Abbott 1930*, 25). Then, how does the recorded frame rate of 16 fps of the Kinora images relate to the speed of rotation on the Kinora viewer? The average rotation speed of the Kinora viewer is not explicitly mentioned in most of the literature, however some sources indicate an average duration of 25 to 30 seconds for playing a Kinora reel in the viewer (*Lewis 2008*, 37, *Queraltó 2013*, 72). Based on a reel with 640 images, this means a frame rate of 21-26 frames per second. In the case the Kinora images were recorded with an average frame rate of 16 fps, they would be displayed in the viewer with a higher speed. As a result, the images would appear slightly accelerated. The optimal speed of rotation of the viewer thus depends on the frame rate in which the Kinora images are recorded. In the case of 16 fps, the rotation speed should be slowed down to match the speed in which the images have been recorded.

153 As mentioned before, the images of our replica reel were based on an analogue film that was originally recorded with a frame rate of 16 fps. For the comparative tests, however, we decided to export the image sequence at different speed ratios: 12.8 fps (80%), 16 fps (100%) and 25 fps (156%). We conducted the tests with a digital metronome, which we set to three speeds as well: 60 rpm (one revolution per second), 90 rpm (one and a half revolution per second), and 120 rpm (two revolutions per second). We furthermore compared the replica reels with the original Kinora reels in our tests, to see at which speed the movement of the images appeared naturally. We found that the rotation speed of 60 rpm, so one revolution per second, gives the most natural results of movement in the case of the normal speed of 16 fps. The rotation speed of 60 rpm seemed most natural also in the case of the British Mutoscope and Biograph Kinora reel depicting a parade.

154 The optimal speed of rotation of one revolution per second equals a frame rate of 14.6 fps, as calculated earlier in relation to the kinematics of the system. This number approaches the 16 fps frame rate, corresponding to the average recording speed of the time. However, this result would mean, contrary to the hand-cranked Lumière Cinématographe and Pathé-Baby 9.5 mm film projectors, the optimal speed of rotation of the Kinora was not two revolutions but a little bit more than one revolution per second in the case of a 16 fps recorded image frame rate. This optimal rotation speed would make a total duration of 43.75 seconds per Kinora reel.

155 Reflection: opportunities and challenges

156 Within this part, we would like to elaborate on the main opportunities and challenges that we faced in the Kinora 3D replication process from both an experimental media archaeology and mechanical engineering perspective.

157 Opening up the "black box"

158 Starting with the media historical and experimental media archaeological point of view, the hands-on approach and use of 3D modelling and printing enabled us to investigate and “open up” the Kinora as a historical media technology. One of the main advantages of working with a replica rather than the original object was the ability to conduct user tests without running the risk of damaging the original object. Testing the optimal distance between the lens and the image, for instance, would not have been possible with the original object because this distance is not flexible but fixed in the case of our Kinora viewer. As such, the 3D replication processes enhanced our understanding of the original object's materiality and functionality. In particular, they enhanced our understanding of the main principles of the Kinora as a technological system, for instance the function of the small metal stop attached to the viewer's guidance to arrest, disassociate and flatten the Kinora images during the rotation. By means of replicating this part we better understood the function of the image's curvature: when the flattened image flips, it goes back to its original curved state so it won't block the view of the next image in the viewer. The processes of 3D replication and hands-on experimentation with both the original and replica objects, in other words, made us better understand and *experience* the direct interrelationship between the materiality, design and functionality of the Kinora as a motion picture technology and media historical object.

159 Besides a better understanding of the principles behind the functioning of the Kinora system's main parts (i.e. the lens hood, worm gear mechanism, flexible arm, guidance and stop), the replication process also led to a greater comprehension of some of the material characteristics of the Kinora that are usually not described in the historical sources and literature. For instance, we did not expect to find such large differences in the dimensions of the two types of Kinora reels in our collection, the one produced by the Mutoscope and Biograph Company and the other by the Kinora Company and Bond's Limited. What was the reason for this difference? Was this because of problems with the functionality of the system, or perhaps due to patent reasons? Questions like these necessitate a further investigation of the materials and technologies available at the time of production, and the techniques and processes used thereby. How were the Kinora reels produced? How were the photographic image cards cut? Investigating the material differences of the Kinora reels led to new questions and made explicit some of the system's developments through time.

160 The hands-on approach was furthermore helpful to reconstruct the technological affordances and constraints of the Kinora as a technological system from the perspective of its (intermedial) design and histories of use. Why did the shape of the lens hood mirror the design of a stereoscope? Why use two lenses instead of one in the lens hood of the viewer? Our finding that changing the distance between the two lenses within the lens hood has no

significant impact on the image sharpness made us wonder why the Kinora was not designed with one singular lens instead. Was this because the lenses at the time were not strong enough, so the extra magnification resulting from the combination of lenses was necessary for optimizing the viewing effect? Or was this rather the outcome of a design choice, in which the comfortability or familiarity of the viewing position played an important role (i.e. making the Kinora viewer correspond to the design of the table stereoscope, which was a popular domestic instrument at the time, see: *Brown, Anthony 1999*, 171)? Addressing these technical, design and user-related issues inspires us to further investigate the history of magnification in media history as well as the (dis)continuities in optical media and film projection devices in general.

161 From the point of view of mechanical engineering and desktop manufacturing, the making of the Kinora replica particularly brought opportunities for the application of the 3D modelling and printing technologies available in the Engineering 3D Lab. The replication process furthermore made us reflect on the similarities and differences with the mechanical engineering technologies and techniques that were used to produce the original Kinora viewers and reels at the time, more than a century ago. In addition to the more historically-driven and epistemologically-oriented questions of how the 3D replication of the Kinora could be used as a heuristic method to reconstruct and understand the seemingly simple mechanism of this historical motion picture technology, how it worked and how it was used in the past, the engineering perspective was interesting particularly in relation to the methodological question of how 3D modelling and replication could also be used as a way to adapt, adjust or even improve the functionality of the original object. For example, by exploring the possibility to make the lens hood flexible or adding a motor-drive to the viewer. This flexibility in design, use of materials and addition of new features opened up new possibilities for the testing of our parameters (i.e. parameter 1 and 2 in the case of the flexible lens hood, parameter 4 in the case of an added motor). On the other hand, it would also make the replica historically less “authentic”, a tension which often created a productive exchange within our interdisciplinary collaboration.

162 Historical authenticity

163 One of the main challenges of the project was to make the Kinora reel replica compatible with the original Kinora viewer and, vice versa, plus make the original reel compatible with the replica viewer. This mutual compatibility was required for our comparative user tests and hands-on experiments. While the first prototype of the replica reel was compatible with both the original and replica viewers, as described above, the original Kinora reels were not compatible with the first prototype of the replica viewer. The challenge was to adapt to the different variations of the sizes and dimensions of the original reels. Since the inner diameters of the “early” Kinora reel produced by the British Mutoscope and Biograph Company and the “late” Kinora reel produced by the Kinora Company and Bond's Limited differed significantly, we had to increase the diameter of the large pin as well as the distance between the small and large pins on the replica viewer. Only in this way, would both types of Kinora reels be able to fit. Instead of adapting our 3D model to either one of the two reels, we thus implemented a flexible design that allowed for compensating the different dimensions of the reels. This flexible design sometimes impacted the degree of historical authenticity we were able to achieve during the replication process.

164 The question to what extent the replicated object matches the characteristics of the original object is naturally at stake when making a replica. The notion of historical authenticity (or historical accuracy, see: *Carlyle 2020*) is therefore necessarily addressed in historical projects dealing with replication and reconstruction methodologies. The importance and degree of historical authenticity, however, depends on the aims of the project (*Philosophical Café 2021*). Curatorial and exhibition projects in museums, for instance, aim to make a replica that comes as close as possible to the materiality, shape and physical properties of the original object (*Wilson, Stott, Warnett, Attridge, Smith, Williams 2018*), whereas in educational and research projects the design and functionality of the object have greater importance. In our case, striving for historical authenticity was not our main objective. Instead, as mentioned, the central aim of the project was to make a *working* replica that could be used for comparatively testing several parameters in order to better understand the Kinora as a technological system. While we tried to stay as close as possible to the original Kinora in terms of its materiality, design, size and functionality, we often had to make several compromises.

165 These compromises in historical authenticity were made for different reasons. Costs and time efficiency is one of them. For instance, our decision to use prefabricated magnifiers instead of recreating the lenses in the Kinora lens hood ourselves allowed us to keep the process in our own hands and not rely on other parties for the development. The compromise was that it slightly affected the size of the lens hood in the design of the replica viewer. Other compromises were related to the capacities of the 3D printing technologies that we used in the lab or the efficiency of the printing process in general. The original dimensions of the teeth on the worm gear, for instance, were too small (< 0.4 mm) for our 3D printer to replicate. As a consequence, we had to increase the size of the worm gear on the replica viewer. Changing the angle of the small support plate from 45 degrees to 60 degrees serves as another example of how we adapted our design within the replication process.

166 Compromises in historical authenticity were furthermore naturally caused by the type of materials that we had chosen to use in the replication process and their qualities. The earlier described challenge that we encountered with the friction of the worm gear and worm shaft examplified this. Costs and time efficiency motivated our choice to use PLA plastic materials for most of the parts of the replica viewer, instead of steel like in the original. The changes in the design of the three prototypes of the viewer replica reflect how this led to several compromises. To make the replica viewer fully functional and mutually compatible with the original Kinora reels, we had to adapt the design, change the dimensions and add several elements that were not part of the original viewer. For example, we added three bearings to support the worm shaft and several screws on the support plate. While these added elements provided more support and so enhanced the stability of the worm gear mechanism, they also made the replica less authentic compared to the original. Replacing some of the plastic parts and 3D-print them instead in wood (i.e. support plates), sheet metal (i.e. the stop feature) or onyx nylon (i.e. gear and worm shaft) to match the material qualities of the original viewer, eventually contributed to making the replica viewer functional. In a way, changing the material types for these parts made the replica more historically authentic as well.

167 Conclusion

168 Replicating the Kinora as a historical motion picture technology through the processes of 3D modelling and printing has resulted in a working replica viewer and reel that are mutually compatible with their original counterparts. In addition to these working replicas, the 3D replication process has produced new knowledge about the Kinora as a technological object, in particular the relationships between its materiality, design and mechanical functionality, which were helpful for reconstructing its (historical) practices of use. In this concluding part of the article, we reflect on the epistemological and methodological values of 3D modelling and desktop manufacturing as heuristic methods in doing digital history and media historical research in a hands-on and interdisciplinary way.

169 3D modelling and printing as heuristics

170 Epistemological value

171 Replicating the Kinora was valuable from both an epistemological and a methodological point of view. The possibility to "open up" the Kinora in the 3D modelling phase and to conduct hands-on experiments in the comparative user tests allowed for combining the practices of (historical) imagination with the actual hands-on testing of certain functionalities. This generated new insights and led to a better understanding of the mechanism of the Kinora as a historical motion picture technology as well as its histories of use and production. Consequently, we experienced that using 3D modelling and desktop manufacturing techniques together with hands-on experimentation, provides an ideal interdisciplinary form of hands-on digital media history "thinkering". Testing the four parameters of the optimal distance between the lens and image, the optimal magnification and distance between the lenses, the optimal thickness of the photographic images cards, and the optimal rotation speed made us not only think *about* the technological mechanism but also think *with* it. The hands-on experiments raised all sorts of questions about, for instance, the physics behind and histories of the Kinora's lens configuration, the factors determining the size and sharpness of the images in the viewer, the speed of rotation, and the influences of the compression and thickness of the image cards on the system's rotational velocity. Testing those parameters made us reflect on the place of the Kinora as a motion picture technology within the history of cinema in general and, in particular, its genealogy (*Gaudreault, Marion 2002*). After all, as argued by various film scholars and media archaeologists, the first moving images were not projected on a large screen, but rather viewed individually in a box (*Domankiewicz 2021*, 3). Similar to the Kinetoscope and the Mutoscope, the *dispositif* of the Kinora enabled such an individual viewing experience up to twenty years after the invention of cinema. Through the process of replicating the Kinora we were able to better grasp – both literally and figuratively – how exactly this viewing experience has been shaped and constrained by the object's mechanism, materiality, design, shape and size. Historical changes in this configuration – such as the dimensions of the worm gear and thickness of the photographic paper – are important signs and indicators in the negotiation processes between inventors, engineers and users regarding the "interpretative flexibility" (*Bijker, Hughes, Pinch 1987*) of the Kinora as a domestic motion picture system.

172 Opening up the Kinora as a media historical "black box" furthermore made us more aware of the intermedial relationship between the Kinora as a motion picture technology and related media technologies of the so-called times of "pre" and "early" cinema. These include the Zoetrope and Phenakistoscope, which are similarly based on the physiological principle of "persistence of vision" to generate the illusion of movement, but also the stereoscope that mirrored the design of the Kinora's lens hood. As a hand-operated apparatus in which the user directly controls the speed of the images, the Kinora furthermore connects to contemporary digital media technologies. For example, to the smartphone as a medium and the ways in which it configures or mediates a tactile relationship with the user (i.e. via the touch screen) and thereby affords a direct way of controlling, manipulating and interacting

with the displayed images. Replicating the Kinora allows for making such diachronic connections explicit on the basis of hands-on practices and the experiential knowledge achieved through them.

173 **Methodological value**

174 Methodologically, the replication of the Kinora made us more conscious about the use (and potential misuse) of 3D modelling and printing in historical research (*Menotti 2020*). The application of the 3D modelling and desktop manufacturing techniques in the Engineering 3D Lab made us constantly reflect on and (re)negotiate the balance between the functionality of the replica and the level of historical authenticity it represents. We found that the notion of "adaptation" plays a central role in this, especially when 3D replication processes serve as a heuristic method. Approaching 3D replication as heuristic and adaptive processes stimulates the historical imagination. It arguably brought us closer to those inventors, producers, engineers and tinkerers of the time and the ways in which they must have adapted themselves to the materials and manufacturing techniques available for solving the technical and functional problems of the technology they had been creating or developing further. Drawing on the terminology of experimental media archaeology, thinking in terms of adaptation consequently provides the perspectives of the "re-enacted user" (*Fickers, van den Oever 2019*, 49) as both a consumer and producer of the Kinora as a historical media technology. Methodologically, the 3D replication process consequently helped us as a heuristic method to bridge the gap between the past and the present, the engineer and the historian, contemporary and historical strategies of adaptation in both the technological design and production processes.

175 Final words and future steps

176 Although the Kinora seems largely forgotten as an early 20th century motion picture technology and home cinema system nowadays, it still speaks to the imagination of many film historians, collectors and archivists who have recently (re)discovered it as an object and material carrier of national or local film history. In 2017, for instance, the National Film and Sound Archive of Australia (NSFA) made an effort to digitize various original Kinora reels from their collection (*Gall 2017*), and in 2020 the National Library of Scotland reported about their Kinora digitization project, including Kinora reels featuring Scotland's oldest moving images (*BBC News 2020*). Communications around these digitization projects often refer to the Kinora as one of the first home cinema and home movie technologies that provide unique glimpses into early 20th century everyday life. This reminds us of Barry Anthony, who in his book on the history of the Kinora already wrote that those Kinora reels that have remained until today, some of which were taken by amateurs, are dating "from a time when 'home movies' were virtually unheard of. [...] [T]o see 'ordinary' people performing such acts in the years before the First World War brings the past into a more immediate and poignant perspective." As such, they offer us "a unique glimpse into a now lost world" (*Anthony 1996*, 18).

177 With our Kinora replica project we have aimed to contribute to a better understanding – both historically and technologically – of how the Kinora as a remarkable motion picture technology worked and how it was used in the past. As heuristic methods, 3D modelling and printing engineering techniques were used to produce working Kinora replicas that can serve as models for further research, development and experimentation. One of the next steps we would like to take includes the production of an "improved" prototype of the replica viewer that facilitates a motor-driven operation, similar to those luxury models of

the original Kinora viewer. Such a motor-driven version of the Kinora viewer would allow us to automatize the rotation speed and so test more systematically the relationship between the optimal frame rate and the speed of rotation in the viewer. Another idea for further research and development is the making of an improved Kinora viewer replica specifically designed for the digitization of original Kinora reels. We have already received signals of interest in such an apparatus from various cultural heritage institutions with Kinora reel collections. A final next step involves the making of a working replica of the Kinora camera as a media historical object, which would make our replication project of the Kinora system complete.

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